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American Institute of Electrical Engineers

COMING MEETINGS

Pacific Coast Convention, Salt Lake City, Utah, Sept. 7-10

MEETINGS OF OTHER SOCIETIES

National Electric Light Association

East Central Division, Cedar Point, Ohio, July 13-17
Rocky Mountain Division, Glenwood Springs, Col., September 13-16
New England Division, Poland, Maine, September 21-23

Illuminating Engineering Society, Spring Lake, N. J., September 7-10

Wisconsin Utilities Association, (Electrotechnical,) Eau Claire, Wis., September 3-4

Association of Edison Illuminating Cos., Quebec, September 27-October 1.

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Journal of the A. I. E. E.

Devoted to the advancement of the theory and practise of electrical engineering and the allied arts and sciences

Vol. XLV July, 1926 Number 7

The Investigation of Engineering Education

On June 10, Dr. Jewett, National Secretary Hutchinson and the undersigned met in conference with Messrs. Wickenden and Hammond, representatives of the Society for the Promotion of Engineering Education, for the purpose of discussing the following findings and recommendations of the Board of Investigation and Coordination regarding Engineering Education:

"1. There is no present need for the further multiplication of degree-granting colleges of engineering. The moral influence of the colleges and of the national engineering societies should be used to discourage the multiplication of weak professional schools and to encourage the growth of schools devoted to vocational training for junior and intermediate forms of technical work.

"2. On the initiative of the S. P. E. E. the national engineering societies might properly cooperate with the colleges in defining an acceptable or recognized engineering college for the support of satisfactory educational standards among the colleges and for the guidance of the societies in applying the provisions of their constitutions and by-laws which relate to conditions of admission to membership and the recognition of student chapters and branches.

"3. Engineering colleges should be encouraged to give up the practise of awarding such professional degrees as "Civil Engineer," "Mechanical Engineer," and the like, for programs of academic work. On the initiative of the S. P. E. E. the national engineering societies might properly cooperate in recommending a basis for the awarding of professional degrees which would have the approval of the several professional societies and would be consistent with the requirements for entrance to a professional grade of membership.

"4. There is a strong sentiment in the professional societies in favor of engineering curricula which are only slightly or moderately differentiated from each other. The program of undergraduate work in the colleges should emphasize largely the broad foundations of engineering and should assume that much of the special training needed for particular types of engineering work should be obtained either by graduate study or in connection with active experience.

"5. It is desirable that there should be a standing council on engineering education; that the initiative toward this end should originate in the S. P. E. E., as representing the colleges; and that the national engineering societies should accept the invitation, if given, to appoint representatives in such a council."

The several conferees expressed themselves as being in sympathy with the above propositions. It was recognized, however, that this attitude would not commit either organization in an official way. The propriety of having national organizations of the engineering industries represented in the joint advisory council on engineering education was discussed, it being the sentiment that such representation would not be desirable at the outset because of the greater mutuality of interest existing between the professional societies and the engineering schools.

This conference was in response to a letter addressed by our Past President, Dr. Charles F. Scott, to Mr. Calvin W. Rice, Secretary of the Joint Conference Committee of the Founder Societies. I quote several passages from this letter:

"During the past two and one-half years this Society (S. P. E. E.) has been engaged in a comprehensive study of engineering education. Its broad purposes have been to elevate educational and professional standards and to bring about a closer relationship between the colleges, the engineering societies, and American industry. The Founder Societies have given support and rendered advice to this enterprise through a group of educational councilors. The societies have appropriated funds for conducting special studies of educational matters relating to the several major engineering fields. These studies have paralleled similar studies made by and in the colleges themselves.

"The Carnegie Corporation has financed the enterprise for a period of three years. We now approach the end of that period. Thus far we have secured the active and hearty cooperation of practically all of the engineering colleges and we have made a comprehensive and accurate analysis of the present and past state of engineering education. We have also reached definite conclusions upon which to base recommendations as to the future course of engineering education. It remains to put these recommendations into effect. We believe that the undertaking should continue beyond the stage of fact-gathering and analysis to which it has thus far been largely devoted and that its next stage should be one of effective action. We believe that the national engi-

neering societies should share with the colleges the responsibility for the support and direction of such effort.

"To this end we hope we may obtain from the Founder Societies endorsement of our purpose to continue the enterprise and to bring about constructive action. We therefore suggest that each of the Founder Societies participate in its financial support through a small appropriation. We feel that such support will be of great importance in two ways: first, in giving the societies a share in the direction of the enterprise, and second, in assisting us to obtain additional support from other sources. Since our undertaking has been essentially of the nature of engineering research it would seem appropriate for Engineering Foundation to aid in financing it by appropriation and assistance in obtaining contributions."

Dr. Jewett, Secretary Hutchinson, and the undersigned approved in principle Mr. Wickenden's findings and agreed to recommend them to Board of Directors of A. I. E. E.

The President of A. I. E. E. and its National Secretary attended a meeting of the Joint Conference Committee called by Secretary Rice for June 15, 1926. At this conference the following resolution was adopted:

VOTED: to approve the continuance of the research in the field of engineering education now being conducted by the Society for the Promotion of Engineering Education, which research would otherwise be terminated December 31, 1926, and each President in turn is to recommend to his Board a small appropriation, say approximately ten cents per student in the respective branch of engineering corresponding to the field of endeavor of each of the four Societies. This would approximate annual appropriations as follows:

American Institute of Electrical Engineers	$1,800.
American Society of Civil Engineers	1,600.
American Society of Mechanical Engineers	1,200.
American Institute Mining & Metallurgical Engineers	250.

It is further understood that this approval is limited to a program which it is expected would be concluded within two years.

This whole subject was laid before the Board of Directors of A. I. E. E. at its meeting at White Sulphur Springs on June 23. At this meeting, the following telegram was received and read:

Society Promotion Engineering Education rejoices in splendid cooperation already accorded and the support now proposed by engineering societies and Engineering Foundation in movement to broaden develop and enrich engineering education. Convention at University of Iowa earnestly hopes governing bodies of societies will approve recommendations of their Presidents.

(Signed) Charles F. Scott.

The Board of Directors recommended to the Finance Committee of A. I. E. E. to provide in its budget for the years 1927 and 1928 appropriations of approximately $2000 for the support of the splendid enterprise in which the membership of A. I. E. E. is deeply interested.

I do not hesitate to endorse every sentiment in this matter expressed by our Past President, Charles F. Scott.

M. I. PUPIN.

Some Leaders of the A. I. E. E.

H. B. Buck, twenty-ninth president of the A. I. E. E., 1916-1917, was born in New York City, May 7th, 1873. He graduated from Yale University in 1894 with the degree of Ph. B. and received his degree of E. E. from Columbia School of Mines in 1895. The year 1895-1896 was spent as a student in the shops of the General Electric Company at Schenectady, and during this period, Mr. Buck did much experimental work on a-c. apparatus for the great scientist, Doctor Steinmetz.

From 1896 to 1900, Mr. Buck was assistant to the chief engineer of the Lighting Department of the General Electric Company, Schenectady, in which capacity he had much to do with the introduction of high-tension, a-c. distribution in many of the large central stations of this country, he traveling extensively throughout the United States to accomplish this work. During that same period, he also had charge of the experimental work which led to the development of the oil switch and other high-tension devices which furthered power operation by alternating current.

In 1900 he was chosen chief electrical engineer of the Niagara Falls Power Company and allied interests at Niagara, having entire charge of electrical engineering in the design and construction of powerhouse No. 2, on the American side of the Falls and the Canadian Niagara Power Company's plant on the Canadian side; also the terminal stations at Buffalo, and engineering in connection with the distribution of Niagara power in Niagara, Tonawanda and Buffalo. In 1906, in cooperation with Mr. E. M. Hewlett, at Niagara Falls, Mr. Buck carried on experimental work on high-tension insulators which resulted in the development and introduction of the suspension insulators now in universal use.

Since 1908 Mr. Buck has been vice-president of Viele, Blackwell and Buck, New York City, engaged in the design and construction of hydroelectric and steam power plants and large transmission systems both in the United States and Canada. Among these might be mentioned work for the Great Western Power Company of California, the Appalachian Power Company, the Northern Ontario Light & Power Company, the Great Northern Power Company and many others.

In 1925 the International Commission made him consulting engineer on the investigation of the development of some 4,000,000 h. p. at various sites on the St. Lawrence River between Ogdensburg and Montreal.

Regenerative Braking for Direct-Current Locomotives

BY A. BREDENBERG, JR.[1]

Non-member, A. I. E. E.

Synopsis—*This paper gives a comparative study of several d-c., regenerative braking systems now in successful operation. The general characteristics of regenerative braking, including advantages, limitations and functions are briefly discussed. The principal points covered in the descriptions of the various systems are: method of field excitation during regeneration, compensation for sudden changes in line voltage or grade, method of control, operating characteristics and relative complication of equipment.*

Several systems are described in which the regenerating motor fields are excited by a separate generator provided for that purpose, and then other systems are described in which the fields are excited by one or more of the traction motors. Under the former heading are included C. M. & St. P. freight locomotive with a line driven motor-generator set for excitation, the Mexican locomotive with a dynamotor-driven, motor-generator set for excitation and the axle generator system. The applications described under the latter heading are the C. M. & St. P. gearless passenger, the Paulista and the Spanish Northern locomotives.

A comparison is made of these two methods of field excitation, based on a six-motor, two-speed, 3000-volt locomotive. Curves are included illustrating the speed-braking characteristics and also the motoring characteristics. The conclusions drawn from this comparison are that, in general, the separate excitation system is to be preferred on account of the greater braking effort and greater speed range provided. Since the motor excitation system can be provided with less additional expense, it is desirable to consider this method when the expense of the separate excitation system does not seem justifiable.

It is not the purpose of this paper to give an exhaustive discussion of the question of regenerative braking, but to make a comparative study of some of the systems now in successful operation on direct-current locomotives.

General Characteristics

Whenever it is proposed to electrify a railroad, where grades exceeding 0.6 per cent form an appreciable part of the line, usually the possibility of applying regenerative braking is considered on account of its marked advantages. These are, briefly, as follows: (a) Reduced wheel- and brake-shoe wear; (b) increased safety due to reduced tire heating and brake-shoe wear and to the fact that duplicate braking systems are provided; (c) higher average speed descending grades, since a very uniform speed can be maintained; (d) elimination of delays due to inspections, worn out brake shoes, etc.; (e) saving of power returned to the line, and (f) increased comfort to passengers as a result of the uniform speed and elimination of noises and shocks caused by the air-brake system. Against these advantages must be balanced the increased weight, cost, and maintenance of the equipment.

Although regenerative braking may be used to reduce train speeds to a certain extent, and systems have been designed to slow down a train or car to very low speeds, yet the primary purpose of this method of braking as applied to heavy traction service is to hold the train at a uniform speed on a given down grade. Regenerative braking should not be overemphasized as an emergency braking system. This method of braking can only be applied to the locomotive, whereas, in the air-brake system, the brakes may be applied to every car in the train. Therefore, regeneration does not replace the air-brakes or lessen their required reliability but it should be considered as a means of braking, supplementing the air-brakes with some very decided advantages as outlined.

Of course, regenerative braking is particularly applicable to long heavy mountain grades and is generally used in such service because of its obvious advantages. It is applicable to comparatively light or short grades provided the results obtained are commensurate with the extra cost incurred.

In order to raise the voltage of a d-c. series motor to make it return power to the line, it is necessary to excite separately the series field and to control this excitation so that smooth operation is obtained regardless of changes in line voltage or grade.

Methods of Field Excitation

There are two general methods of exciting the motor fields and both of these have been successfully applied. One method is by the use of a generator which may be driven by a motor operating from line voltage or from a dynamotor. Also, it might be mechanically driven from an idle axle of the locomotive.

The other method is to use one or more of the traction motors to excite the fields of the remaining motors. This method may be sub-divided further according to the method of controlling the exciter field. Thus, in one case, the exciter field is controlled by contactors, resistors, etc., especially provided for that purpose, while in the other case, control of the exciter field is obtained by means of the same contactors and resistors that are used in accelerating the locomotive.

C. M. & St. P. Freight Locomotives

The method of exciting the regenerating motor fields by means of a motor-generator set operated from the line voltage was first put into commercial use on the

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1. Railway Equipment Engineering Dept., General Electric Co., Schenectady, N. Y.

Presented at the Annual Convention of the A. I. E. E., White Sulphur Springs, W. Va., June 21-25, 1926.

Chicago, Milwaukee and St. Paul 3000-volt freight locomotives. By reference to Fig. 1, which shows the regenerative connections of one-half of one of these locomotives, it may be seen that the exciter is so connected that the exciter armature current is the sum of the motor field current and the regenerated current. Control of the exciter field is obtained by means of a motor-operated rheostat, automatically controlled by a current-limit relay which is connected in the exciter armature circuit. The current-limit relay thus is responsive to the sum of the motor armature and field currents. Control of the braking speeds is obtained by

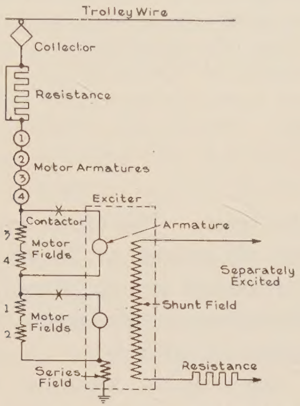

Fig. 1—Diagram of C. M. & St. P. Freight Locomotive

changing the setting of the current-limit relay by means of the braking handle on the master controller.

Compensation for sudden surges in current, due to changes in line voltage or grade, is obtained by a combination of several factors, viz., the differential series field of the exciter, the exciter armature reaction, and the resistance drop in the exciter armature circuit. For example, assume a sudden decrease in line voltage. This will tend to rapidly increase the regenerated current and consequently the current through the exciter armature. The compensating factors will then operate as follows: The differential series field and the exciter armature reaction will tend to weaken the exciter field and reduce the exciter voltage, thus reducing the motor field current, while the increased resistance drop will cause the exciter armature circuit to absorb more of the exciter voltage and thus further reduce the field current and generated voltage of the traction motors. Likewise, a sudden decrease in regenerated current will be compensated for in just the opposite manner. Thus, the inherent characteristics of the exciter circuits prevent excessive surges of current and torque and allow time for the circuits to readjust themselves to the changed operating conditions.

Mexican Locomotives

Another application of the method of exciting the motor fields by means of a separate motor-generator set is that of the Mexican Railway, 3000-volt locomotives. In this case, the regenerative exciter is driven by a 1500-volt motor, which is connected to the mid-point of a 3000/1500-volt dynamotor. Connections for this locomotive are shown in Fig. 2. Here the exciter carries the motor field current only. Control of locomotive speeds is obtained by adjusting the exciter voltage by means of a variable resistance in the exciter field circuit. This adjustment is obtained directly by means of the braking handle of the master controller.

Compensation against sudden surges in line current is provided for by balancing resistances which carry the sum of the field and armature currents. Thus, if the line voltage drops suddenly, it will tend to produce a rapid increase in regenerated current. The increase in current causes an increased voltage drop across the balancing resistance which causes a decreased voltage and current in the motor field circuit. This reduces the regenerated voltage of the motors, thus preventing an excessive change in regenerated current. Similarly, when passing from one control step to another, the balancing resistance aids in producing smooth operation by reducing current and torque increments between steps.

Comparison of C. M. & St. P. and Mexican Locomotives

By comparing these applications, it will be seen that in one case the exciter carries the sum of the motor armature and field currents while in the other case the

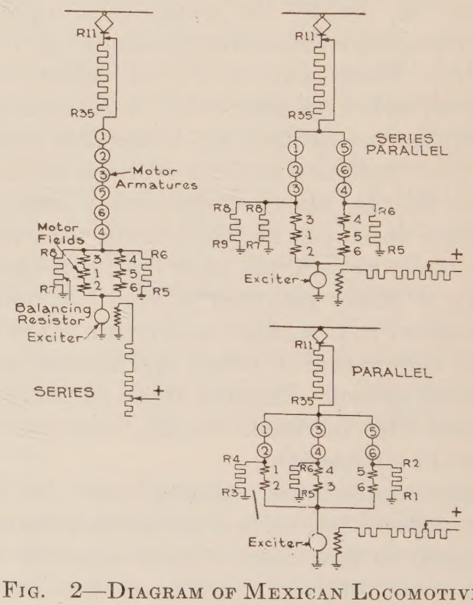

Fig. 2—Diagram of Mexican Locomotive

exciter carries the field current only. This means that, in the latter case, the exciter armature current will be halved. At the same time, the exciter voltage will be increased as the exciter must overcome the voltage drop in the motor fields and also in the balancing resistance. Experience has demonstrated the fact, however, that the drop through the balancing resistance can be held to such a value that the net result is a reduction in kilowatt capacity required of the exciter.

In the first system described compensation is ob-

tained by means of exciter differential field, armature reaction and resistance drop. In the second system, a resistance alone is used since tests and operating data have demonstrated that a very effective compensation can thus be provided. The second system will tend to be less efficient on account of the losses in the balancing resistances. A much simpler control is thus provided, however, and furthermore it is very easy to make adjustments by providing taps in the balancing resistances.

Compared with the other type, the system used on the Mexican locomotives has the characteristic of relatively small changes in speed with regard to changes in the braking effort required. The result is that changes in grade or curvature will cause smaller speed changes in this case than in the C. M. & St. P. System. In brief, the Mexican system tends toward a constant speed characteristic while the C. M. & St. P. System tends toward a constant torque characteristic.

The ideal characteristic for regenerating motors would be a characteristic similar to that obtained in motoring operation with a series motor where the armature and field currents are equal throughout the operating range. This would give a very stable electrical characteristic but an extremely unstable speed characteristic, as the braking effort would decrease very rapidly with increases in speed.

The ideal characteristic from a mechanical standpoint would be one in which the speed on any controller notch is held constant regardless of changes in braking effort required. Such a characteristic would be approximated with constant field excitation. Such a system would be very unstable electrically, however, as very large changes in armature current would occur with small changes in speed. This would be particularly undesirable at high speeds on account of the relatively weak fields required.

In practise, a compromise must be made between these two extremes. From the standpoint of train operation, it is very desirable to obtain a uniform speed for any given controller notch. Some speed variation must be allowed, however, in order to obtain the desired stability of the motors. Such is the case with the two systems described above. In each case, for any given controller notch within the regenerating range of the motors with increases in speed a sufficient increase in braking effort is obtained to give mechanical stability, but, at the same time, the speed regulation is not made so close as to sacrifice the desired electrical characteristics.

With the more constant speed characteristic of the system used on the Mexican locomotives, very little manipulation of the master controller is required to hold the train at a practically constant speed. This has been demonstrated in actual operation on the Mexican Railway. The electrified section of this railway is 45 kilometers long and regeneration is obtained for about two-thirds of this distance, the grade being about 4.7 per cent the greater part of the way.

The principal advantage of the Mexican system is its simplicity. Compensation for line-voltage changes is obtained by means of a simple resistance, and control of the regenerating speeds is obtained by hand control of a resistance in series with the exciter field. No relay or motor-driven rheostat is used. This will reduce the first cost of the system and keep the maintenance required down to a minimum.

Development of Method of Control of Exciter Field

The steps in the development of the method of controlling the exciting generator field included experiments with the sensitive type of regulator used with stationary units. Later, the motor-operated field rheostat was used and finally direct hand control of the field was adopted, compensation against voltage and speed fluctuations being obtained by the inherent characteristics of the motor field circuits without the addition of any regulator or moving parts.

Axle Generator System

The axle generator system may be considered as a motor-generator set system in which the motor of the motor-generator set is replaced by the axle driving mechanism. The same method of control may be used in either case.

The principal differences between an axle generator system and the corresponding motor-generator set system are that the axle generator is necessarily a slow-speed machine, it varies in speed with the speed of the locomotive, and the driving torque of the axle generator is available to aid in braking the train.

Assuming that the same connections are used for an axle generator system as are used on the Mexican locomotive (Fig. 2), it may be readily seen that, with an increase in speed due to an increase in the grade, the regenerated voltage and current will tend to increase due to the increase in speed of the motors themselves and also to the increase in speed of the axle generator which thus tends to increase the motor field current. This helps to give a very close speed characteristic for any given excitation of the axle generator field, such being desirable provided the electrical stability of the motors is not lessened.

Regarding the added braking effort of the exciter, this might prove an advantage in freight service where it is often desired to handle a considerably heavier train down grade than could be hauled up the same grade by one locomotive. In this case, however, it will probably be necessary to use the air brakes on the train in conjunction with the regenerative braking so that little would actually be gained from the additional braking effort obtained from the axle generator. Furthermore, there must be an idle axle available to drive the exciting generator. This is usually the case with passenger

locomotives. On freight locomotives, however, there are very often no idle axles, as illustrated by the Mexican and Spanish Northern locomotives and the Paulista freight locomotives, where every axle drives a traction motor.

Another limitation of the axle generator is that, due to its low speed, it must be of relatively large size. In addition, it must deliver practically the same output over a wide range of speeds, which will tend to compromise the design and complicate the control. Furthermore, the axle generator is mounted close to the track and thus is subject to more abuse, dust particles, etc., than a generator mounted in the locomotive cab.

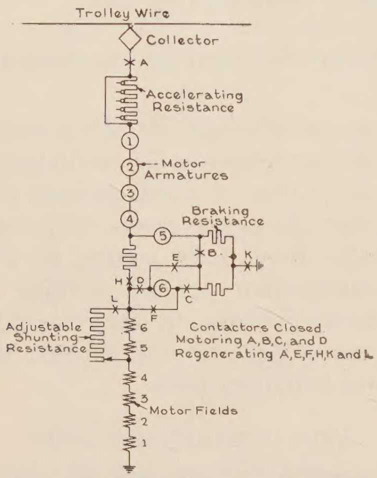

Fig. 3—Diagram Regenerating Connections of C. M. & St. P. Gearless Passenger Locomotive

C. M. & St. P. Gearless Passenger Locomotives

In order to eliminate the use of a separate generator for field excitation, the method of using one or more traction motors as a regenerative exciter was developed. The first application of this system to heavy-traction service was on the C. M. & St. P., 3000-volt, gearless, passenger locomotives. Fig. 3 shows the regenerating connections for one-half of the locomotive. The two halves may be operated in series or in parallel when regenerating so that two combinations of regenerating motors are obtained, one with eight motors in series and the other with two parallel groups, of four motors in series, in each. In each six-motor group, two of the traction motors are used to excite the fields of all six motors. Control of the excitation is obtained by means of a variable resistance, which shunts the fields of the exciting motors. This resistance is adjusted by means of contactors controlled by the braking handle of the master controller.

From the connections, it will be seen that the sum of the field and armature currents of the regenerating motors passes through the two exciter armatures which are connected in multiple and that an external resistance is connected in series with each of the exciter armatures. This system thus provides an inherent regulation against line-current surges which is in effect a combination of the C. M. & St. P. freight and the Mexican systems. That is, the sum of the armature and field currents of the regenerating motors passes through balancing resistances and also through the exciter armatures. An effective means of compensation against surges is thus provided.

A further simplification of the apparatus required for regeneration may be obtained with the traction-motor exciter system by using the same resistances and contactors for controlling the exciter during regeneration that are used during acceleration of the locomotive. This system is now in successful operation on the Paulista locomotives (four-motor, 3000-volt) and on the Spanish Northern locomotives (six-motor, 3000-volt). On the Paulista locomotives, one traction motor is used to excite its own field and the fields of the other three motors which are connected in series to the line. On the Spanish Northern locomotives one traction motor is used to excite its own field and the fields of the other five motors which are connected in series to the line.

Paulista Locomotives

Fig. 4 shows the schematic connections of the Paulista locomotive both motoring and regenerating. It will be seen that there are two motor combinations motoring, one with all four motors in series with 750 volts applied per motor and the other combination with two groups of two motors in series in each with 1500 volts applied per motor. There is one regenerating combination with

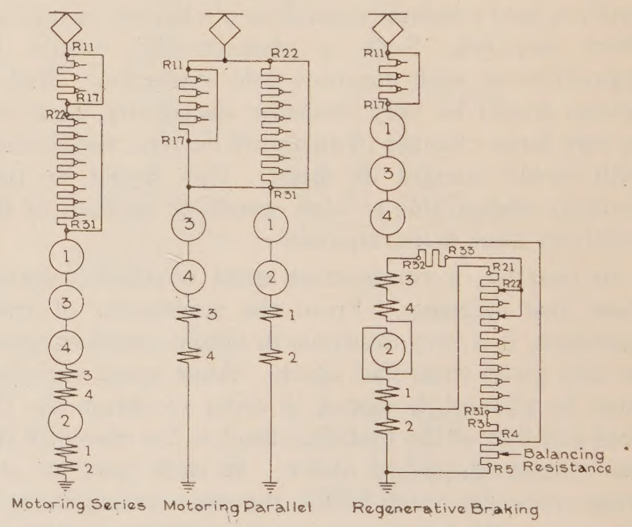

Fig. 4—Diagram of Schematic Connections of Paulista Freight and Passenger Locomotive

the three regenerating motors connected in series with a normal voltage of 1000 volts per motor. By referring to the resistance symbols it will be seen that part of the accelerating resistance is connected in series with the regenerating motors. This resistance is used in connecting the motors to the line when establishing the regenerative connection. It is short-circuited during regeneration. The remainder of the accelerating resistance is connected in the motor field circuit and is

thus used to control the regenerative operation. Some additional resistance and additional contactors are required but it is to be noted that an appreciable saving in equipment is made by using the accelerating resistance and contactors for control of the exciter field.

Practically the same method of compensation for line current surges is used as on the Mexican locomotives. A balancing resistance is connected in the circuit so as to carry the sum of the line current and the exciter field current. This exciter field current is also part of the regenerating motor field current so that the compensation is obtained in two ways; directly by the effect of the balancing resistance on the regenerating motor fields, and indirectly by the effect of the balancing resistance on the exciting motor field.

Spanish Northern Locomotives

On the Spanish Northern locomotives there are two motoring combinations, one with all six motors in series

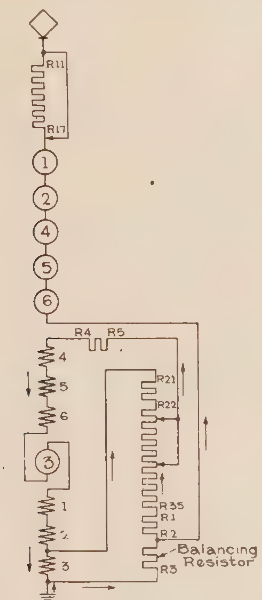

Fig. 5—Diagram of Regenerating Connections of Spanish Northern Locomotive

with 500 volts applied per motor and the second with two parallel groups of three motors in series in each with 1000 volts applied per motor. Fig. 5 shows the regenerating connections of this locomotive. One of the six motors is used to excite its own field and the fields of the other five motors which are connected in series to the line with a normal voltage of 600 volts per motor. The regenerating system is otherwise identical with that of the Paulista locomotives.

Comparison of Methods of Field Excitation

In order to obtain a comparison of the system using a separate generator for field excitation and that using traction motor excitation a study was made of the operating characteristics of a locomotive similar to the Spanish Northern, six-motor, two-speed, 3000-volt locomotive as compared with the same locomotive with a motor-generator set for field excitation. For motor excitation, then, there will be one regenerating combination with one traction motor exciting the other five, all connected in series. For separate excitation there will be two regenerating combinations, one with all six motors in series and the second with two parallel groups of three motors in series in each, these combinations being the same as those obtained while motoring.

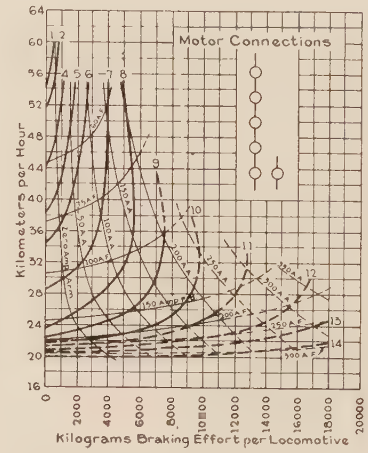

Fig. 6—Speed-Braking Effort Curves for 86-Ton, 6-Motor, 3000-Volt Locomotive with Traction Motor Excitation

In comparing the operating characteristics of these two systems of regeneration, the main points to be considered are as follows: range of operating speeds, train weights which may be handled, slope of grades, mileage on which regeneration can be used, and reliability.

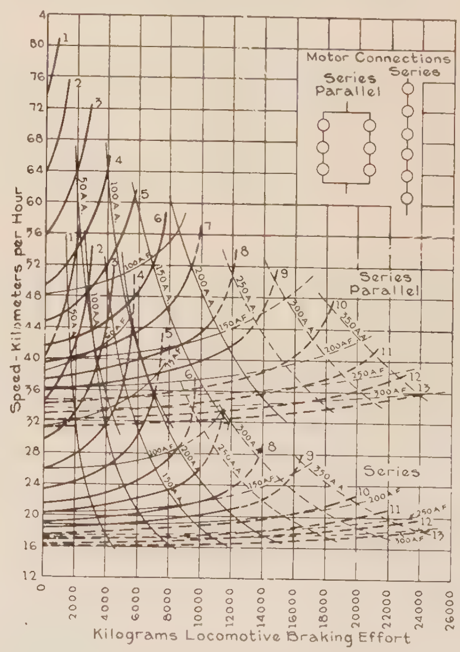

Fig. 7—Speed-Braking Effort Curves for 86-Ton, 6-Motor, 3000-Volt Locomotive with Separate Excitation

Figs. 6 to 8 inclusive illustrate the speed-braking effort characteristics obtained with the two systems. Figs. 6 and 7 give the relation between speed and

braking effort for each step of the braking handle on the master controller, and Fig. 8 is a composite diagram which shows the range of speeds and braking efforts which may be obtained in each case. The shaded areas in Fig. 8 give the continuous operating ranges while the unshaded areas give the ranges within which the locomotive may regenerate for short periods. This diagram also shows the speed-traction effort curves for motoring operation in each of the two motoring connections. In each case the full field and two reduced field characteristics are given. The tractive effort and speeds at the continuous current rating are also indicated.

Two regenerating speed ranges are obtained with the separate excitation system whereas one speed range is

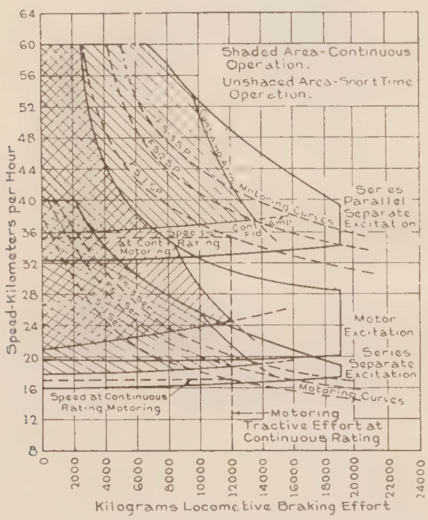

FIG. 8—COMPARISON BETWEEN SEPARATE AND TRACTION MOTOR EXCITATION FOR 86-TON, 6-MOTOR, 3000-VOLT LOCOMOTIVE

obtained with motor excitation, this latter speed range being intermediate to the two speed ranges with separate excitation.

In analyzing these curves, it is to be noted that with the same line voltage, the same motor combination, and the same armature and field current, a slightly higher speed will be obtained when regenerating than when motoring. The reason for this is the reversal of the effect of resistance drop in the motor circuits. Under the same conditions the braking effort regenerating will be appreciably greater than the corresponding tractive effort motoring on account of the reversal of the effect of the motor losses on the torque at the driving wheels. Furthermore, with a given torque at the driving wheels, it will be possible to handle a considerably heavier train down grade than up grade since the train and curve friction oppose the locomotive ascending the grade while they assist the locomotive when descending.

With the separate excitation system, therefore, the regenerating speeds will be a little higher than the motoring speeds with the same motor combination, voltage, and currents. With motor excitation of fields, in this particular case, the regenerating speed at the continuous-current rating of armatures and fields will be about 70 per cent of the corresponding motoring speed. As a rule, the double-speed range is to be preferred unless it is desired to descend the grade at a lower speed than used in ascending. In the latter case the speed range of the motor excitation system will probably be more suitable.

From an analysis of the curves, it may be seen that for a given armature and field current of the regenerating motors a greater braking effort is obtained with the separate excitation system than with the motor excitation system. The reason for this is that, in the former system, the full braking effort of all six motors is available while in the latter the full braking effort of five motors is available and a fraction of the full braking effort of the exciting motor. The result is that greater train weights can be handled down a given grade with the separate-excitation system than with the motor-excitation system.

The following conclusions in regard to operating characteristics may be stated as a result of the comparison of these two systems:

1. With motor excitation in general, on all grades, the same train can be handled down hill as up hill, but at reduced speeds. This reduction in speed will be comparatively small for light grades but will increase as the grade increases.

2. With separate excitation at continuous current, armatures, and fields, a considerably heavier train may be handled down hill than up hill and at a slightly greater speed. The percentage difference in the size of the train thus handled decreases as the grade increases.

3. With separate excitation, a train may be handled down grade at a considerably higher speed than this train can be hauled up the same grade, assuming that the safe operating speed is not exceeded. The percentage difference in these speeds decreases as the slope of the grade increases.

This study indicates that motor excitation may best be applied to a line with comparatively light grades; *e. g.*, one and one-half per cent and under. It will still be applicable to heavier grades if these grades are short and little time is lost on account of slower speeds, or if the slower speed obtained will not handicap the schedule speed desired.

Regeneration with separate excitation is particularly applicable to heavy grades; *e. g.*, two per cent and over, when the length of these grades is an appreciable part of the total length of the line. It is also preferable to use this system for lighter grades when it is necessary to take advantage of the highest speeds possible down grade.

Concerning reliability of operation, there will be little difference if any, between the two systems, assuming that the same rugged type of equipment is used in each

case and that the same method of compensation is used as has already been described.

It is evident that the additional expense of providing for regeneration is less with motor excitation than with separate excitation since in the former case less additional equipment is required.

It is to be noted that the foregoing comparison covers the specific case of a two-speed, six-motor locomotive. The same general considerations would apply to a similar comparison for any two-speed locomotive. For locomotives with more than two motoring speeds or combinations, there will be cases where motor excitation cannot be so readily applied on account of the limited speed range which can be obtained. This would be the case, for example, with a three-speed locomotive such as the Mexican locomotive. The logical regenerating combination in this case would be that of one motor acting as an exciter for the other five motors in series. The speed range thus obtained would be quite low in comparison with the highest motoring speed which is obtained with three parallel groups of two motors in series in each. Other combinations could be worked out for this type of locomotive, but with a reduction in braking torque which would, of course, be undesirable. To other types, such as the C. M. & St. P. gearless passenger locomotive, motor excitation can be more readily applied. This locomotive has four motoring combinations; viz., with twelve, six, four and three motors in series across the line. Two regenerating combinations are obtained with eight regenerating motors in series and two parallel groups of four motors in series. Thus, a better speed-range regenerating is obtained than with the six-motor, three-speed locomotive cited above.

It is not within the scope of this paper to discuss all possible combinations to which motor excitation may be applied. From the foregoing discussion, however, the conclusion may be drawn that this type of regenerative braking may be readily applied to two-speed locomotives in general and in some cases to locomotives with a greater number of motoring combinations.

In the foregoing discussion, it has been attempted to present the characteristics of certain types of regenerating systems which have been successfully applied to d-c. locomotives. In general, it may be stated that a system with a separate generator for excitation of the motor fields is to be preferred as this gives the same motor combinations regenerating as motoring and furnishes the full torque of each motor for braking the train. Since the motor excitation system can be provided with less additional expense, however, it is desirable to consider this method when the expense of the separate excitation system does not seem justifiable. In any application, before a decision is reached as to the type of braking system to be used, a thorough study should be made of all the contributing factors.

The High-Speed Circuit Breaker in Railway Feeder Networks

BY J. W. McNAIRY[1]

Non-member

Synopsis.—*A method of isolating grounded sections of extensive feeder networks supplying power to railways without disturbing the power supply to other sections has long been desired by railway engineers. This has been successfully accomplished by utilizing the inherent characteristics of the magnetic type of high-speed circuit breakers in the manner described in this article. These characteristics are (a) high-speed operation, (b) discriminating characteristic, (c) reduction in trip point with reduction in line voltage, (d) polarized characteristic.*

A description of an experimental investigation on an equivalent network for a representative section of feeder system, made up by using reactors and resistors, has been given. Complete selective operation, isolating defective feeder without disturbing the power supply to interconnected feeders, was obtained for all locations of the short circuit.

Breakers of the type used successfully on d-c. networks can be applied to a-c. networks and the advantages of high-speed protection realized on this type of system. High-speed operation is very effective in reducing telephone interference during short circuits on the a-c. railway system.

Introduction

THE development of the high-speed circuit breaker and its application to the d-c. railway system has contributed greatly toward reduced maintenance and increased reliability of the power supply of this system. The effectiveness of the high-speed operation of this device in reducing the duration of short circuits and limiting the current, thereby eliminating flashovers of commutating apparatus and reducing the damage from arcs at points of fault, has been well recognized for a number of years. The elimination of flashovers and the reduction in the damage to windings of motors and other apparatus, connecting cables and mechanical equipment coming into contact with fallen contact lines or faulty cables, has reduced to a minimum the duration of power interruptions from this source.

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With a few minor exceptions, high-speed circuit breakers applied to d-c. railway networks have been of the magnetic type, one form of which is shown by Fig. 1. This type involves the principle of a contact arm held in the closed position against a strong spring by a holding armature across the poles of an electromagnet. A tripping coil is interposed between the holding coil and the armature and is so connected that current through this coil exerts a m. m. f. to reduce the flux in the retaining armature, at the same time increasing the flux through a suitable magnetic by-pass circuit without an appreciable change in the flux through the

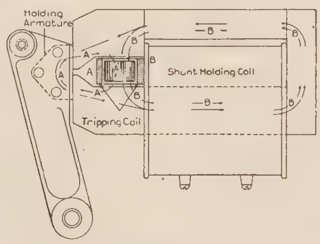

Fig. 1a

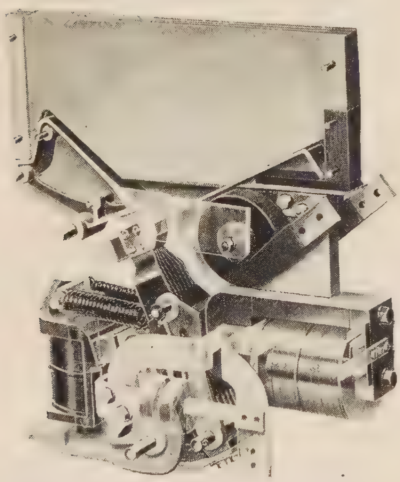

Fig. 1 b

1a—Magnetic Circuit of the Holding and Tripping Coils of the High-Speed Circuit Breaker

1b—Phantom View of a 600-Volt, D-C., High-Speed Circuit Breaker

core of the main holding coil. As the tripping current is increased, the flux is shifted in this manner from the holding armature to the magnetic by-pass circuit without the necessity of changing the flux interlinking the main holding coil. The effectiveness of this arrangement is such that the armature is released practically instantaneously when current in the trip coil reaches a predetermined value, regardless of the rate at which this current is increasing.

There are certain inherent characteristics in this type of circuit breaker which introduce possibilities for selective operation between breakers applied to a d-c. railway network, in case of short circuits, in such a way as to isolate defective feeder sections without the interruption even momentarily, of the power supply, to interconnected sections. The results obtained by proper utilization of these characteristics are comparable to those obtained on the usual a-c. networks by selective relay systems of the various well-known types.

The remainder of this article furnishes a detailed explanation of these characteristics and the methods of utilizing them, together with a description of the results obtained during an experimental investigation on a representative network.

Characteristics of the Magnetic Type High-Speed Circuit Breaker

The following inherent characteristics of the magnetic type of high-speed circuit breaker contribute most to the solution of problems of selective operation on a d-c. railway network:

a. High-speed operation

b. Discriminating characteristic providing a reduction in the trip point during a rapid current rise

c. Reduction in trip point with a reduction in line voltage

d. Polarized characteristics.

I. High-Speed Operation

In order to fully protect commutating apparatus in the d-c. railway substation, machine breakers must operate sufficiently fast to prevent flashover in case of short circuits inside of the station. While short circuits inside of station feeder breakers occur infrequently, without high-speed operation of protecting breakers, the current is relatively great and the resultant damage to substation apparatus is likely to be serious. This consideration automatically precludes the use of relays or any other selective system which delays the operation of such circuit breakers even slightly under short-circuit conditions.

The selective operation of the magnetic type of high-speed breaker is based upon an arrangement whereby the current is limited by the breaker or breakers supplying the faulty feeder directly, before the trip point of similar breakers supplying interconnected feeders, or the machine breakers in the substation is reached. During d-c. transients with an initial current rise of hundreds of thousands of amperes a second, the speed of operation of the breakers feeding such a short circuit must be relatively high. This is essential in order that advantage may be taken of conditions or arrangements whereby the trip current of one breaker is reached in advance of the others. These breakers must operate fast enough to limit the current before the trip point of the remaining breakers is reached. The speed of operation of the magnetic type of high-speed breaker designed to operate sufficiently fast to prevent flashovers of commutating substation apparatus is sufficient for such an application.

II. Discriminating Characteristic

The discriminating characteristic of the magnetic type of high-speed circuit breaker is obtained by connecting

an inductive shunt in multiple with the tripping coil, the total current through the breaker being distributed between these two circuits. The distribution of a slowly rising current between the trip coil and shunt is determined by the resistance, (and of a rapidly rising current by the inductance,) of the two parallel circuits.

The trip point of a circuit breaker so equipped can therefore be made a function of the rate at which the current is increasing.

Calculations of Current Distribution Between Tripping Coil and Its Shunt

Where the constants of the external circuits are

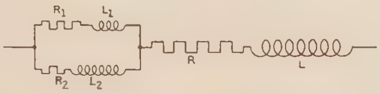

Fig. 2—Graphical Representation of the Resistance and Inductance of the Trip Coil of a High-Speed Circuit Breaker in Parallel with its Shunt and the Combination in Series with a Feeder

known, the current through the trip coil at any instant can be calculated as follows:

Referring to Fig. 2,

L_1 = Inductance of tripping coil
L_2 = Inductance of tripping coil shunt
L = Inductance of the external circuit
R_1 = Resistance of tripping coil
R_2 = Resistance of tripping coil shunt
R = Resistance of external circuit
I_m = Final current external circuit
= E/R where E applied voltage
t = time

$$I_1 R_1 + L_1 \frac{d I_1}{d t} = I_2 R_2 + L_2 \frac{d I_2}{d t} \qquad (1)$$

$$I_2 = I - I_1 \qquad (2)$$

$$\frac{d I_2}{d t} = \frac{d I}{d t} - \frac{d I_1}{d t} \qquad (3)$$

L_1, L_2, R_1 and R_2 are negligibly small in comparison with L and R;

$$\therefore I = I_m \left(1 - e^{-\frac{R}{L} t}\right) \qquad (4)$$

Substituting (4) in (2):

$$I_2 = I_m \left(1 - e^{-\frac{R}{L} t}\right) - I_1 \qquad (5)$$

Also from (4):

$$\frac{d I}{d t} = I_m \frac{R}{L} e^{-\frac{R}{L} t} \qquad (6)$$

Substituting (6) in (3):

$$\frac{d I_2}{d t} = I_m \frac{R}{L} e^{-\frac{R}{L} t} - \frac{d I_1}{d t} \qquad (7)$$

Substituting (5) and (7) in (1):

$$L (L_1 + L_2) \frac{d I_1}{d t} + L (R_1 + R_2) I_1 = I_m (L_2 R - R_2 L) e^{-\frac{R}{L} t} + I_m R_2 L \qquad (8)$$

Solving for I_1:

$$I_1 = \left[\frac{I_m (L_2 R - R_2 L)}{L (R_1 + R_2) - R (L_1 + L_2)} \right] e^{-\frac{R}{L} t} + \frac{I_m R_2}{R_1 + R_2} + c\, e^{-\left(\frac{R_1 + R_2}{L_1 + L_2} t\right)}$$

Substituting the value of c, when at $t = 0$, $I_1 = 0$:

$$I_1 = \left[\frac{I_m (L_2 R - R_2 L)}{L (R_1 + R_2) - R (L_1 + L_2)} \right] \left[e^{-\frac{R}{L} t} - e^{-\frac{R_1 + R_2}{L_1 + L_2} t} \right] + \frac{I_m R_2}{R_1 + R_2} \left[1 - e^{-\frac{R_1 + R_2}{L_1 + L_2} t} \right]$$

The time of maximum I_1 can be found from the relation:

$$\frac{d I_1}{d t} = I_m \left(\frac{R_1 + R_2}{L_1 + L_2} \right) \left(\frac{L_2 R - R_2 L}{L (R_1 + R_2) - R (L_1 + L_2)} \right) e^{-\frac{R_1 + R_2}{L_1 + L_2} t} - I_m \left(\frac{R}{L} \right) \left(\frac{L_2 R - R_2 L}{L (R_1 + R_2) - R (L_1 + L_2)} \right) e^{-\frac{R}{L} t} + \frac{I_m R_2}{L_1 + L_2} e^{-\frac{R_1 + R_2}{L_1 + L_2} t} = 0$$

Or:

$$t = 2.3026 \left(\frac{L (L_1 + L_2)}{R (L_1 + L_2) - L (R_1 + R_2)} \right) \log_{10} \frac{(L_1 + L_2)(L_2 R - R_2 L)}{L (R_1 L_2 - R_2 L_1)}$$

The curves of Fig. 6 were calculated in this manner.

Transient Currents During Short Circuits and Under Normal Loads

The ratio of inductance to resistance of the usual railway circuit fed by a given circuit breaker involving the motors of cars or locomotives under maximum normal load conditions is usually considerably higher than that of the feeder circuit alone when a short circuit occurs at the maximum distance from the circuit breaker. A typical comparison is shown by the curves of Fig. 3. By taking advantage of this difference the magnetic type of high-speed circuit breaker can be equipped with an inductive shunt proportioned to trip the breaker at current values considerably lower than the steady load setting with a short circuit through the maximum length of feeder without danger of too frequent operation by transient currents encountered under normal load conditions.

In addition, the mechanical speed at which the magnetic type of circuit breaker opens after the trip point is reached is affected, to some extent, by the amount the trip coil current is increased in excess of that required for tripping the breaker. The force for accelerating the contact arm of the circuit breaker is the difference between the tension of the main springs and the holding effect of the armature flux. As the current

through the tripping coil is increased, a greater resultant force is available for accelerating the contact arm mechanically. The curve of Fig. 4 shows this relation between the force available for accelerating the contact arm and the current through the trip coil.

The inductive shunt in multiple with the trip coil is, therefore, not only effective in reducing the trip point

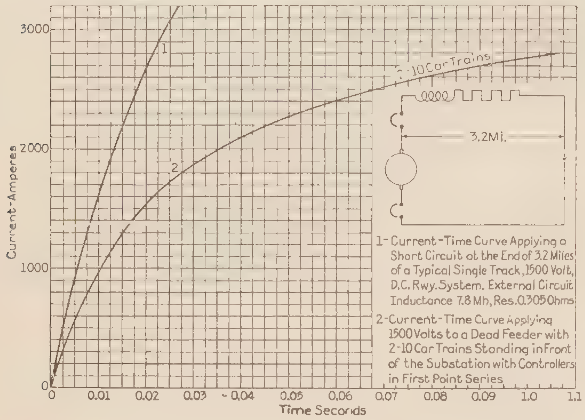

Fig. 3—Curves Showing the Difference in Rate of Current Rise Caused by Applying a Short Circuit at the Distant End of a Feeder and Energizing a Dead Feeder with Load in the Other Substation

of the circuit breaker under short circuit conditions, but is also effective in forcing a greater percentage of the line current through the trip coil after the trip point is reached with a consequent greater mechanical speed of operation of the circuit breaker under conditions where selective operation is desired.

A breaker of this type can be made to operate fast enough, in many instances, to limit the maximum current during a short circuit to a value below the normal overload setting. Such a breaker will "discriminate"

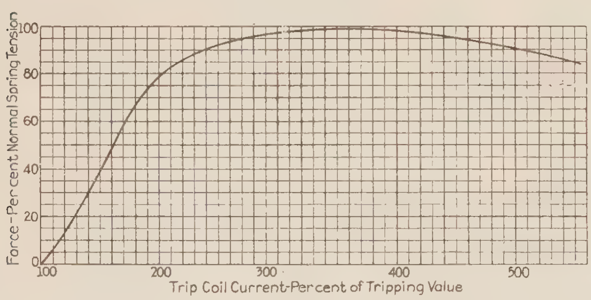

Fig. 4—Resultant Force for Accelerating Contact Arm of the Magnetic Type of High-Speed Circuit Breaker

between normal overloads and short circuits, and this characteristic is frequently referred to as the discriminating characteristic of the circuit breaker. The amount of discrimination is limited only by the transient currents, encountered under normal load conditions.

This discriminating characteristic contributes greatly to the selective operation between breakers, both in substations and in the complete feeder network.

Selective Operation Between Feeder and Machine Breakers

For selective operation in the substation, it is the practise to equip the feeder breakers with inductive shunts which impart a decided discriminating characteristic. The high-speed breakers for machine protection have no discriminating characteristic; that is, their trip point is independent of the rate at which the current is rising. A short circuit on the feeder of a substation so equipped, in most cases, will be cleared by the feeder breaker without tripping the machine breakers and interrupting power to the station bus and other feeders. This statement applies for a majority of short circuits where only one machine is operating in the substation and both machine and feeder breakers carry the same short-circuit current because of the reduction in trip point and faster operation of the feeder breaker.

Where the total machine capacity connected to the station bus is considerably in excess of the capacity of the feeder as is usually the case during important traffic periods of the large systems, short circuits within several hundred feet of the station on the ordinary feeder will open the feeder breakers without operating the machine breakers.

Selective Operation Between Breakers in the External Network

By examining Fig. 5, the function of the discriminating breaker in the external net work may be better understood.

Nos. 1, 2, 7, and 8 are substation feeder breakers and Nos. 3, 4, 5, and 6 are sectionalizing tie breakers.

Assuming a ground occurring at *S* on feeder *B* near

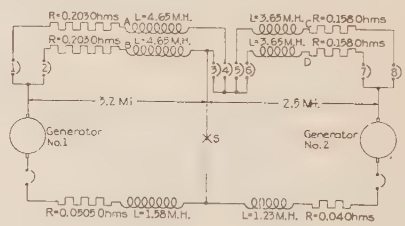

Fig. 5—Equivalent Network for a Typical Double-Track, 1500-Volt, D-C. Railway System, Showing Location of Circuit Breakers

the tie station, the rate of increase of current and the current at any instant through breaker No. 3, due to the short circuit, will be the sum of currents through the three breakers, Nos. 1, 7, and 8. Breaker No. 3 will, therefore, trip at a very much lower value than that required to trip either of the three breakers Nos. 1, 7, or 8, and will operate fast enough to limit the total current to a value considerably below the total required for tripping any of these three breakers feeding the short circuit through the tie station.

The short circuit, under such a condition, will be cleared by breaker No. 3 at the tie station and breaker No. 2 at the substation without interruption of power

to feeders *A*, *C*, or *D*. The discriminating characteristic is effective under these conditions in reducing the trip point and in speeding up the operation of breaker No. 3 so that the short-circuit current is limited to a value considerably below that necessary for tripping the other feeders.

It also reduces the trip point of breaker No. 2 sufficiently to operate it even though the resistance of the feeder limits the current to a value below the steady overload setting.

It can be stated in general that as the number of feeders interconnected through a tie station is increased, the selective operation between the breakers feeding a short circuit directly and the breakers feeding interconnected feeders is more easily obtained. This may be explained as follows: With a certain number of interconnected feeders, when a short circuit occurs on one feeder a certain proportion of the current on this feeder will flow from each other feeder. With a larger number of interconnected feeders the current in this feeder will be larger in proportion to the current in each of the other feeders. Also the current in this feeder will more quickly rise to the tripping point of this feeder's breaker. And this in effect means that the selective action of the system increases when the number of feeders is increased.

III. Reduction in Trip Point with Reduced Line Voltage

The holding coil of the magnetic type of high-speed breaker can be excited from the main feeder circuit when desired. When so connected, the trip point is a function of the line voltage. When breakers having their holding coils so excited are connected in the feeder network at some distance from the substation during a short circuit, the trip point of any breaker will depend on its distance from the fault, the nearest breaker having the lowest trip point. Breakers which are identical in every respect, connected in the same feeder at some distance from each other and subjected to the same short-circuit current, can be operated selectively in this manner in such a way that only the breakers adjacent to the fault open.

Under such conditions when a short circuit occurs at a sufficient distance from the substation to include a sectionalizing breaker, such as on a feeder near the sectionalizing tie station of Fig. 5, the current rise is sufficiently slow to allow time for the desired change in the holding-coil current and results in the operation of the tie breaker before the short-circuit current reaches the trip point of a similar breaker near the station, the holding-coil current of which is not appreciably affected by the short circuit.

The curves of Fig. 6 may be taken as typical and apply to the system shown by Fig. 5 with a short circuit on feeder *A*, with power fed from station No. 1 only, breakers No. 1, 2, 3, and 4 only closed.

The rate at which the holding current is reduced under such conditions is easily controlled by regulating the time constant of the holding-coil circuit, and by choosing the portion of the saturation curve of the holding-coil magnetic circuit over which the breaker operates under normal conditions. The breaker can be designed with a highly saturated holding magnetic circuit, so that the trip point is not greatly affected by voltage reductions occurring in normal service, but will have its trip point lowered very rapidly by voltage reductions in excess of a predetermined maximum.

In general, exciting the holding coils from the line does not place objectionable limitations on the transfer of power through a tie station. Referring again to Fig. 5, this point may be illustrated by the following limiting cases:

(1) With a tie station at the extreme end of a double-

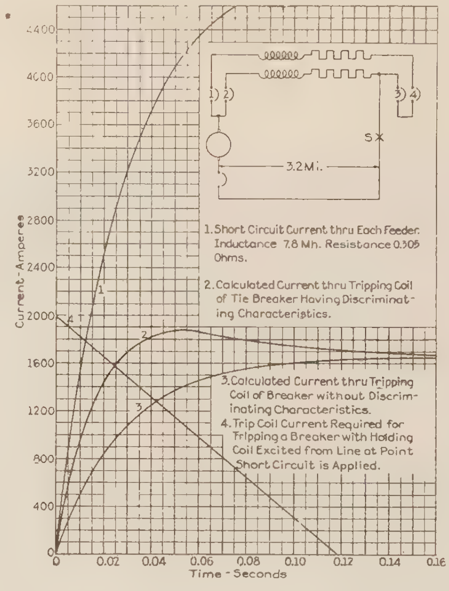

Fig. 6—Current-Time Curves Applying a Short Circuit Opposite a Sectionalizing Tie-Station 3.2 Mi. from Substation on a Double-Track System with Stub-End Feed. Breakers No. 2 and No. 3 Tripped

track system, stub-end feed, the tie breakers will carry only one-half the load under the worst conditions when the load is all on one feeder.

(2) On a large system with many feeders interconnected through a tie station, an excessive load on any one feeder will not greatly reduce the voltage at this point because of the large number of feeders in multiple.

(3) Where heavy loads occur on all feeders near a tie station simultaneously—a condition which results in the greatest voltage reduction—the exchange in current through the tie breakers will be small and the reduction in trip point will not be objectionable. The effects of reduction of voltage at the tie station under normal conditions on the trip points of breakers the holding coils of which are excited from the line is therefore of no great importance for the usual applications.

Protection of Extremely Long Feeders

In addition to the selective possibilities of such an arrangement when applied to large network, reduction in trip point with reduction in line voltage is useful for applications involving unusually long feeders where short circuits at the extreme distance from the station may result in a current rise and a final current no greater or even less than that encountered under normal load conditions. If such a feeder is sectionalized at some distance from the station by a high-speed breaker with holding coil excited from the line, the trip point will be lowered sufficiently to operate on short circuits at the extreme end of the line, thereby preventing annealing of feeder copper or other damage which might otherwise occur if the short circuit is allowed to persist.

IV. Polarized Characteristics

The direction of current required for tripping the magnetic type of breaker is fixed by the polarity of its holding coil.

Referring again to Fig. 5, all of the holding coils of the sectionalizing tie breakers 3, 4, 5, and 6 are excited from the station bus. The polarity of these breakers is fixed so that they trip on current flow from the tie bus to the feeder only. A short circuit occurring in the vicinity of the sectionalizing tie station, such as at *S*, reduces the trip point of all breakers located at this point. The direction of the short-circuit current is correct to trip No. 3 breaker, but assists in holding in breakers 4, 5, and 6. The short circuit under such conditions will, therefore, be cleared by breaker No. 3 without having interrupted the tie between feeders *A*, *C*, and *D*. The polarized characteristic is, therefore, of great assistance in preventing the operation of the breakers feeding power to the tie bus.

Tests on Equivalent Network

A series of tests was made on the equivalent network of Fig. 5 to demonstrate the selective possibilities of the magnetic type of high speed circuit breaker on a representative system.

For approximately uniform spacing between substations and sectionalizing tie stations, selective operation is more easily obtained on networks of the general form of Fig. 5 as the number of tracks and feeders increase. The transient current through that section of the individual feeders between the substation and the fault is not greatly affected by the number of parallel feeders, and the performance of station feeder breakers clearing short circuits on the feeder to which they are connected is therefore not affected. At the sectionalizing tie station the ratio of current rise in the breaker feeding the short circuit direct to the current rise in the several feeders feeding the short through the tie station is increased as the number of feeders is increased, this greater difference resulting in more positive selective operation.

The section of double-track system, the equivalent circuit for which is shown on Fig. 5, was, therefore, taken as representative of the more difficult type of system for selective operation and was used for the experimental investigation.

Equivalent circuits were set up for each feeder using cast-iron resistors and air-core inductance coils.

While both mutual and self-inductance of the parallel copper conductors comprising each feeder of network are easily calculated, calculations of inductance of the rails of the track return are difficult because of skin effect and variations in magnetic permeability.

The values on which the calculations for the equivalent network were based were taken from the data obtained during a series of short circuit tests on an actual system involving a rate of increase of current of the same order of magnitude as that of the equivalent system. The method consisted in calculating the inductance of the copper conductors of the feeder on which the tests were made and determining the inductance of conductors which at the rail locations gave a total inductance equal to that shown by initial current rise.

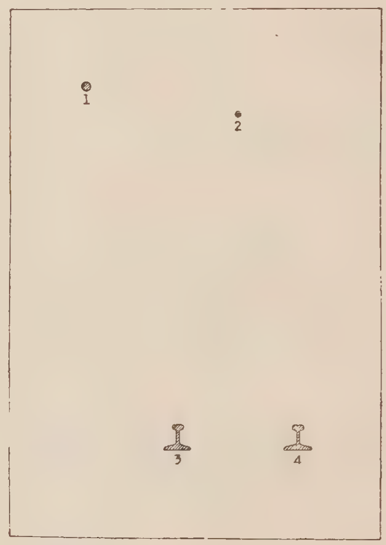

Fig. 7—Cross Section of a Feeder, Trolley Wire and Rails Identified for Calculating the Rate of Current Rise

Air-core inductance coils were necessarily used to represent the total inductance of the positive and negative sections of the feeders.

The self-inductance of these coils was adjusted to give a counter e. m. f. of inductance on the initial current rise equivalent to the total calculated induced voltage of the complete feeder with the same current rise. This voltage is generated both by the self-inductance of the conductors and by the mutual inductance from the other conductors.

The rate at which the current increases in each conductor was determined by solving the following simultaneous equations.

Referring to Fig. 7, in which the conductors are given

numbers that are used as subscripts in the following equations, let E = voltage, L = self inductance indefinite radius, M = mutual inductance:

$$L_1 \frac{d I_1}{d t} \pm M_{1-2} \frac{d I_2}{d t} \pm M_{1-3} \frac{d I_3}{d t} \pm M_{1-4} \frac{d I_4}{d t}$$

$$= L_2 \frac{d I_2}{d t} \pm M_{2-1} \frac{d I}{d t} \pm M_{2-3} \frac{d I_3}{d t} \pm M_{2-4} \frac{d I_4}{d t} \quad (1)$$

$$L_3 \frac{d I_3}{d t} \pm M_{3-1} \frac{d I_1}{d t} \pm M_{3-2} \frac{d I_2}{d t} \pm M_{3-4} \frac{d I_4}{d t}$$

$$= L_4 \frac{d I_4}{d t} \pm M_{4-1} \frac{d I_1}{d t} \pm M_{4-2} \frac{d I_2}{d t} \pm M_{4-3} \frac{d I_3}{d t} \quad (2)$$

$$E = L_2 \frac{d I_2}{d t} \pm M_{2-1} \frac{d I_1}{d t} \pm M_{2-3} \frac{d I_3}{d t} \pm M_{2-4} \frac{d I_4}{d t}$$

$$+ L_4 \frac{d I_4}{d t} \pm M_{4-1} \frac{d I_1}{d t} \pm M_{4-2} \frac{d I_2}{d t} \pm M_{4-3} \frac{d I_3}{d t} \quad (3)$$

$$\frac{d I_1}{d t} + \frac{d I_2}{d t} = \frac{d I_3}{d t} + \frac{d I_4}{d t} \quad (4)$$

The inductive voltage in the positive and negative conductors is then calculated and the air-core coils adjusted for an equal voltage during the initial current rise.

The equivalent circuit involving air-core inductance and cast-iron resistors approximates the actual circuit only because, in the actual system, the time constants of the individual parallel conductors are not exactly the same and as a result the voltage induced by the flux of mutual inductances varies as the current increases. The rate of change of current $\frac{d i}{d t}$ decreases more rapidly in those conductors having a relatively high resistance than in those of lower resistance. This is apparent since the voltage for increasing the current is

$$E_L = E - R I \pm M_1 \frac{d I_1}{d t} \pm M_2 \frac{d I_2}{d t}$$

The mutual inductance (M) is relatively small. E = voltage applied to any conductor and I = current.

The error introduced by the approximate method of using the self-inductance of air-core coils to represent the total inductance of the feeder is well within the limits of accuracy of calibration of commercial breakers for the circuit in question.

Separate calculations for each location of the short circuits were made because of differences in magnitude and direction of the mutual inductance effects with short circuits at different locations. The air-core inductances were adjusted accordingly for each test. The values given on Fig. 5 apply for short circuit at the tie station and were modified slightly for short circuits at other locations.

During the tests the holding coils of substation feeder breakers were excited from an independent constant potential source while sectionalizing tie breakers were excited from the line.

The resistance of the individual feeder of this network

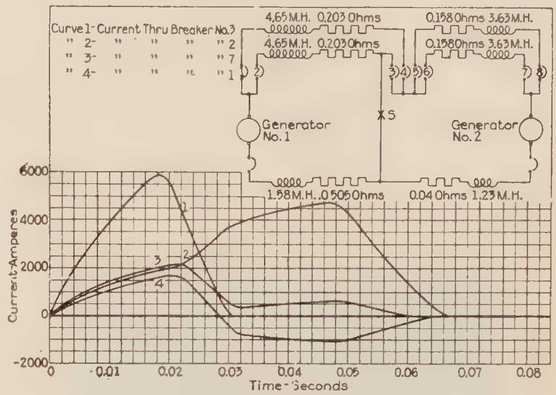

FIG. 8—CURRENT THROUGH VARIOUS BREAKERS DURING SHORT CIRCUIT ON FEEDER NEAR THE TIE STATION OF TYPICAL DOUBLE-TRACK, 1500-VOLT, D-C. RAILWAY SYSTEM. BREAKERS NOS. 2 AND 3 TRIPPED

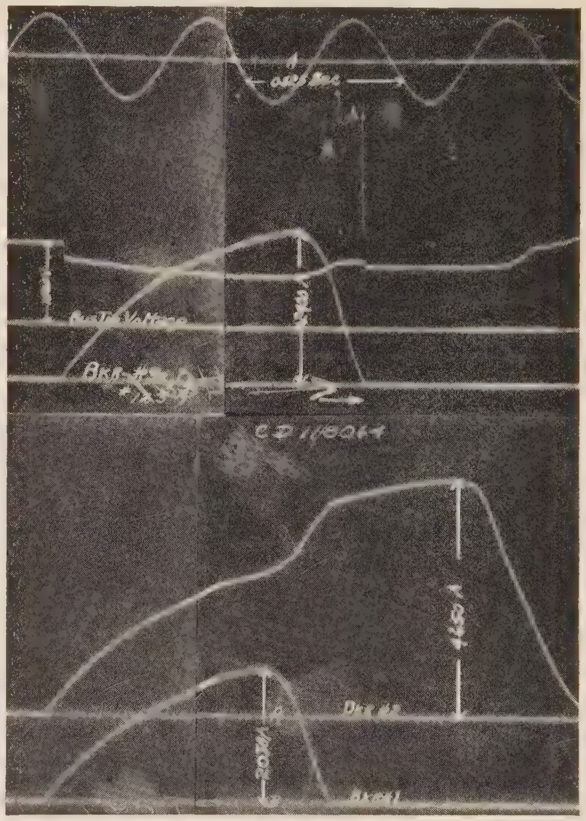

FIG. 9—OSCILLOGRAM OBTAINED WHEN APPLYING A SHORT CIRCUIT TO THE EQUIVALENT CIRCUIT OF A 1500-VOLT, DOUBLE-TRACK SYSTEM, STUB-END FEED AT THE MAXIMUM DISTANCE FROM THE SUBSTATION. SHORT APPLIED AT S, FIG. 5, WITH SUBSTATION NO. 1 SUPPLYING POWER; BREAKER NO. 4 CLOSED. BREAKERS NOS. 2 AND 3 OPENED BY THE SHORT CIRCUIT

is such that the maximum current through each feeder with a short circuit at the sectionalizing tie station is less than the normal load setting required (6000

amperes). The maximum load condition in the individual feeders on a single breaker determined from the train schedules is encountered when restoring power to a dead feeder on which two ten-car trains are standing immediately in front of the substation with their controls in the first point series. The transient currents for these two limiting conditions are shown by the curve of Fig. 3. The current rise when closing the circuit of the two ten-car trains with the control in the first point was interpolated from oscillograms obtained during a series of tests made on a 600-volt system.

Breakers having identical constants were selected for

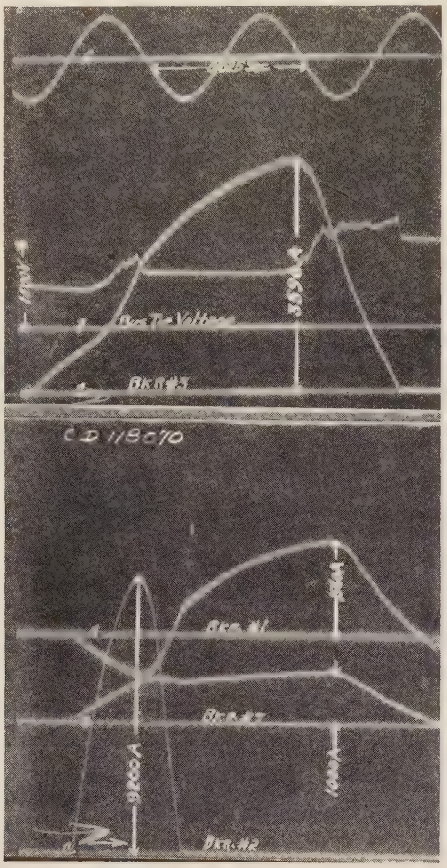

Fig. 10—Oscillograms Obtained when Applying a Short Circuit to the Equivalent Network Shown in Fig. 5. Directly in Front of Substation No. 1 on Feeder B, with All Breakers Closed. Breakers Nos. 2 and 3 Opened by the Short Circuit

all locations on the experimental network. The sectionalizing tie breakers were duplicates of the substation feeder breakers with the exception that their holding coils were excited from the feeders, the holding coils of substation feeder breakers being excited from an exciter bus.

A 1500-kw., 1500-volt generator was used as a power supply for each substation. All breakers were set for a steady overload of 6000 amperes. Selective operation completely isolating the faulty feeders without interrupting power supply to interconnected feeders was obtained for all locations of short circuits applied to the experimental network during the series of tests.

Referring again to Fig. 5, the most important locations tested were as follows:

1. Short circuits on all feeders both directly in front of substations and the sectionalizing tie station,

2. Short circuit on feeder B at the tie station while carrying a 2000-ampere load in the center of feeder D,

3. Short circuits one-half way between substations and tie stations,

4. Short circuit at the substation and at the tie station with a stub-end feed from a substation to the tie station.

The curves of Fig. 8 were taken from oscillograms of a short circuit at S of Fig. 5. Several of the actual oscillograms are shown on Figs. 9 and 10. It is interesting to note that as the short is disconnected from the the tie bus the current increases rapidly through breaker No. 2 speeding up its operation.

While it was not possible to simulate all of the conditions of load and short circuits encountered during the operation of such a system, the results of the tests indicate that it is possible to obtain a high degree of selective operation on d-c. railway feeders by the proper utilization of the inherent characteristics of the magnetic type of high-speed circuit breakers.

Several important installations involving a complete equipment of high-speed breakers designed for selective operation based on the principles discussed in this article have been made in the last few years.

The High-Speed Circuit Breaker In A-C. Railway Network

The discussion in the preceding paragraphs of this article has been confined to the d-c. railway network. A method of operation has recently been developed whereby the same type of high-speed breakers applied successfully to the d-c. railway system for a number of years may be applied to the a-c. network.

By the proper application of a-c. breakers of this type many of the advantages of high-speed protection can be realized on a-c. railway feeder networks. The duration of short circuits and resultant damage to apparatus, particularly in case of an arc, can be limited to a small percentage of that resulting under similar conditions with the usual slow-speed protective apparatus. High-speed protection is also of particular value in eliminating telephone interference during a-c. short circuits.

Furthermore, by taking advantage of the characteristics of the magnetic type of high-speed breaker, a high degree of selective operation can be obtained on a-c. circuits, isolating short circuits in a fraction of the time required with the usual type of protective system involving slow-speed breaker, inverse time relays, pilot wires, and the like.

The Effect of Internal Vacua
Upon the Operation of High-Voltage Cables

BY WILLIAM A. DEL MAR[1]
Fellow, A. I. E. E.

Synopsis.—*It has been known for some time that the internal mechanical pressure of cables is a factor in the quality of the insulation, and that the oil used in impregnating paper for cable insulation has a high thermal expansion which may alter the internal pressure of cables with varying temperature.*

This paper considers the rate of pressure equalization in cables and the relative effects of slow equalization upon long and short cables, indicating that there may be considerable difference in dielectric properties depending on the length and past history in regard to temperature cycles.

Means of overcoming these differences are suggested.

The paper is suggestive rather than demonstrative and it is proposed to publish a sequel giving experimental proofs of the facts stated.

CABLE failures have often occurred which have not been explained to the satisfaction of both manufacturing and operating companies. Their outstanding feature from the manufacturers' standpoint has been the fact that individual lengths of cable withstand severe and prolonged high-voltage tests sometimes extending over a week or more, even after removal from the ducts, but when joined into a long cable, they have been, nevertheless, unable to operate at their normal voltage.

This has naturally led to the belief on the part of the manufacturers that in operation the cables must be subjected to more destructive potentials than they experience in the tests, or in other words, that the trouble is due to transient high voltages.

The only alternative is that, in some way, the joining together of a number of dielectrically strong lengths can result in a dielectrically weak cable.

Until recently, this latter alternative seemed scarcely worth consideration since it was outside the range of reasonable probability, whereas the theory of transients seemed to have some foundation in actual circumstances such as the concentration of failures at certain points, regardless of time or place of manufacture of the cable.[2]

The point of view of the user usually seems to have been that the actual evidences of severe over-voltage are negative, whatever the theoretical evidences in their favor might be. They have discounted the proofs of excellence of the individual lengths of cable, and explained the failures on the assumption that the cables are either impregnated with chemically unstable oil or that the cable is incompletely impregnated, the evidences of which are likely to be found in the cables that fail. This theory has not satisfied the manufacturers because cables impregnated with identical compound have been known to operate satisfactorily at higher electric stresses than those in the cables that failed. The manufacturers agree that practically perfect impregnation is essential to obtaining high dielectric strength but have not considered deficiencies in the impregnation or unstable oil to have been always the root of the trouble.

New information has now come to light, however, which explains how a number of good lengths of cable can be joined together into a bad cable, and the evidence is stronger than that which has been adduced in favor of the theories of abnormal voltage, or of defective cable.

The difference between the short length and the continuous cable, as manufactured in the past, is that the former has its ends open to the atmosphere so that the inside of the cable is at atmospheric pressure, whereas the latter, except near its ends, has an internal pressure independent of that of the atmosphere, by virtue of the continuity of the sheaths and joint sleeves, and the viscosity of the compound.[3]

On this difference, in our opinion, hangs the explanation of many mysterious cable failures.

Causes of Vacua in Cables

Oils, such as are used for impregnation, have an extraordinarily high coefficient of thermal expansion, usually of the order of 0.09 to 0.1 per cent by volume, per deg. cent. This is about ten times that of the metals used in a cable. In order to visualize the effect of this, we may assume that all of this change in volume is concentrated at one end of the cable, and consider what happens when a length of, say, 400 ft. is cooled. If the cable is completely filled when it leaves the factory, which may be assumed to be at about 25 deg. cent., and is then put in a duct at 0 deg. cent., the volume of oil will have shrunk 2.5 per cent so that 10 ft. of the cable will be completely deprived of oil.

In actual fact, this shrinkage will not be concentrated at one place but it will be none the less real and, in the aggregate, will be equivalent to the 10 ft. of cable. Where the distance from the center of a cable to its open ends is several miles the time required for internal readjustment of pressure, with heavy petrolatum compound, may be several years, especially if the

1. Chief Engineer, Habirshaw Cable and Wire Corporation.

2. There is no doubt that transients have been a contributory cause of trouble, especially on large systems.

Presented at the Regional Meeting of District No. 5, of the A. I. E. E., Madison, Wis., May 6-7, 1926.

3. Cable compounds being very viscous, flow slowly, so that in the case of a petrolatum-impregnated cable, the readjustment of internal pressure is necessarily a very slow process, varying from practically zero speed with hard compounds and solid conductors to practically infinite speed with thin liquid compounds and hollow conductors.

cable is lightly loaded. It is thus a matter of vital importance to load high-voltage cables, when impregnated with stiff compound, either prior to or upon the application of the voltage, and to maintain a load sufficient to liquefy the compound until internal pressures have been adjusted.

The contraction of compound in a cable is very beautifully shown by impregnating a piece of cable in a light-colored oil, and transferring it while hot to a dark-colored oil in which it is allowed to cool. The outside of the cable will be the first to lose its heat and the oil will, therefore, solidify there first. Hence, as the oil contracts, it will draw away from the center.[4] The dark grease used for cooling will, however, be sucked into the hollow so that the cable in cross section will present the appearance of a hollow ring of light color with a dark core. A small amount of dark compound will also be found in the outer layers due to diffusion. If the cable were allowed to cool in the open air, instead of in dark oil, the core would be free of oil except for that held in the paper by capillarity. Other vacuous spots will form in the compound as it contracts, either as bubbles or streaks.

Lead, which is used universally for cable sheaths, is peculiar in being almost entirely lacking in elasticity; that is to say, when it is stretched, it does not return upon removal of the stretching force. When a cable is put on a reel at the factory, its sheath is stretched on one side, and when the cable is straightened, to go into a duct, the stretched sheath does not contract, but wrinkles, thereby increasing the internal volume. The amount of this increase may, under favorable conditions, be as high as ½ per cent, so that in a case where the oil constitutes ⅓ the cubic contents, the increased volume would take oil from about 1½ per cent of the cable, an amount of similar order of magnitude to the disappearance of oil due to contraction.

Thus, there are two causes of vacua in cables which are of somewhat similar order of magnitude, both operating simultaneously and of such magnitude they might desaturate a 400-ft. length of cable to the extent of leaving the equivalent of 15 ft. of cable without oil and with a vacuum in its place. Thus, a petrolatum-impregnated cable having atmospheric pressure at 25 deg. cent. when reduced to 0 deg. cent. shows an internal vacuum of 22 or 23 in., as measured by a pressure gage attached to one end. In this condition, ionization will occur at about ⅓ the voltage which would be required at atmospheric pressure.

It is not only in theory or laboratory tests that this phenomenon occurs. The lead sleeves of a large number of splices on high-tension lines have been known to collapse, proving the existence of very low pressure within the cable. Vacua of 15 to 20 in. have been noted in splices of installed cables, and in such vacua, ionization starts at 40 to 60 per cent of the voltage required at atmospheric pressure.

When high-tension cables are installed, it has been frequently observed that air is sucked in when the caps are broken. This absorption of air continues for hours at a diminishing rate. If the joints are applied before the completion of this action, the cable will necessarily start its working career with a partial vacuum.[5]

Harmful Effect of Vacua

Having shown that vacua should exist in cables and then that they do exist, the next question is, do they do any harm?

Again the answer is in the affirmative.

Partial vacua ionize at much lower voltages than air at atmospheric pressure. Hence, a cable, having a partial vacuum within it, will show evidences of ionization at abnormally low voltages, so that ionization may occur even at working voltage or less.

The effect is not a mere corona glow, but a series of active streamer discharges, such as are familiar to us in vacuum tube lamps. These streamers emit rays, probably the ultra-violet, which have the effect of converting petrolatum compound into a solid, flaky substance, often known as *wax* or X.[6] Recent analyses have indicated that this substance has the approximate chemical composition,

$$(C_{12}\,H_{28}\,O)_n$$

It is apparently highly polymerized but of unknown degree of polymerization.[7] It is not a wax.

If petrolatum be placed in a vacuum tube so as to be out of the way of the terminals, but yet impinged upon by the discharge, the surface will be converted into X. This interesting laboratory experiment, due to Mr. E. C. Willman, of Cleveland, enables one to see, in process, the phenomenon which is known in cables only by its results.[8] It has been persistently denied by the manufacturers that the presence of this X is necessarily an indication of imminent failure of a cable and they are supported in this contention by tests on short lengths which continue in operation at very high stresses even after the practically complete conversion of the

4. The same phenomenon may be observed by heating a small beaker of grease to the melting point and allowing it to congeal. When solid, the surface will be funnel-shaped instead of practically flat as when water congeals.

5. A collapsible cap filled with compound may be placed over the ends of a cable when the seals are broken, which will prevent access of air and fill the voids with compound. Such a cap should be left on for several hours, preferably overnight. The use of such caps both in factory and field is the subject of a patent application.

6. Ultra-violet rays have a similar effect upon most oils. In the case of some vegetable oils, the effect is so pronounced that it has been made the basis of a commercial lacquering process.

7. Some experimenters report a very small proportion of nitrogen, but we regard this as too minute to be more than an impurity.

8. It was formerly thought that X was due directly to the electric stress, but it has not been found possible to produce it by stress alone, in the absence of electric discharges.

oil into X, yet cable users have known that, in some way, X formation and cable failure go together. These views are reconciled by the fact that short lengths of cable, such as are tested in laboratories by the manufacturers, will not fail due to X because their internal pressure quickly becomes atmospheric whereas long (installed) lengths are more liable to failure because, with stiff compounds, low pressures persist due to the slowness of pressure equalization. Furthermore, X formation increases vacua because X is less bulky than oil, and as mixed with the residual oil it forms a paste which is stiff and resistant to pressure equalization. If conditions are such as to create X, but yet maintain atmospheric pressure, the cable often will not fail.

A number of short lengths (10 ft. under lead) of cable were submitted to an accelerated aging test, one-half the cables being sealed hot, so as to have partial vacua within them when cool, and the other half allowed to cool with the compound at atmospheric pressure. The preliminary results show the vacuous cables have a much shorter life than those at atmospheric pressure, but difficulties in maintaining the seals have vitiated all experiments as far as quantitative results are concerned. The experiments are, therefore, being continued and Mr. C. F. Hanson expects to report them at a later date.

The Way to Avoid Harmful Vacua

We have seen the cause of vacua in cable, and their baneful results. The next question is, naturally, how can they be avoided?

Before answering this, it should be borne in mind that an installed cable ordinarily has an internal pressure entirely independent of the atmosphere because its sheath and the sleeves of its joints are sufficiently thick and rigid to resist considerable pressure.[9] In order to maintain the inside of the cable throughout at atmospheric pressure, there must be the equivalent of openings to the atmosphere, compounds sufficiently fluid to transmit the pressure from these openings at a speed comparable with that at which thermal contraction occurs and longitudinal oil ducts of sufficient cross-sectional area to assist this action. In most cases the normal spaces between strands will suffice, but for very high voltages, a hollow core or special duct is desirable.

In order to provide the equivalent of openings in the cable or joint these must either be open to the air, or provided with a closed but collapsible part. The reservoir of liquid or semi-liquid oil applied to splices in an invention first used at Cleveland meets the latter requirements,[10] while the liquid oil reservoir system, developed in Italy, meets the former, although neither appear to have been intended for the specific purpose described above.

It should be remembered that pressure equalization is very slow with viscous oils, and differences of pressure should not be allowed to accumulate, but rather should be given an opportunity to equalize as they are forming.

In conclusion, we summarize the following characteristics as among the most essential for the successful performance of high-voltage cables:

1. The compound should be sufficiently fluid or soft at all operating temperatures to permit readjustment of internal hydrostatic pressure at a speed comparable with that at which this pressure is disturbed by temperature variations.
2. Access to the atmosphere or to atmospheric pressure should be provided at points sufficiently close to ensure the communication of such pressure to all of the compound in the cable.
3. Oil ducts (special or incidental) must be provided to assist the transmission of this pressure along the cable.
4. The saturation of the cable should be as perfect as possible so as to provide a minimum of oxygen to be absorbed by the compound.
5. The compound should be as immune as possible from deterioration by the rays generated by electrical discharges.

In addition to these characteristics, which are related to the subject matter of this paper, the cable should have, of course, suitable dielectric strength, dielectric loss and flexibility.

NEW MACHINE MINES COAL BY ELECTRICITY

A new-type electrically driven mining machine is being now tried out in various coal regions of the country. It is a powerful machine that cuts its way into the face of a bed of coal, breaks the coal loose and loads it into mine cars without the exercise of manual labor or the firing of a single ounce of powder or dynamite, such as often cause mine explosions. In a test run, this machine was able to bore its way into a coal seam at the rate of one foot in ten minutes and at a total mining cost of half that prevailing in the hand-working sections of the same mine. The entry driven in coal by the machine is 6 ft. high and 11 ft. 6 in. wide. —*Soc. of Elec. Dev.* May 30th, 1926.

9. A pressure of 35 to 45 lb. per sq. in. will start expansion of 8/64 to 10/64 in. pure lead cable sheath.

10. The Cleveland reservoirs were designed for the purpose of exerting atmospheric pressure "on the mobile compound to prevent the formation of voids during temperature changes," (Report of Underground Systems Committee, N. E. L. A., 1924) but as only the joint compound was mobile, the cables being impregnated with petrolatum jelly compounds, the reservoir appears to have been intended primarily as a protection for the joint rather than for the cable.

11. Emanueli, *Transactions* of the First World Power Conference, 1924, Vol. III, p. 1269, states: "The possibility of manufacturing cables destined to work at such high pressures (130 kv.) depends on careful reduction to a minimum of the gas which is occluded between successive layers of the insulating material," and *Jour.* I. E. E., Jan. 1926, p. 127, referring to the 130 kv. cable in Italy, "Its construction differs from that of an ordinary cable only in the fact that air or gas bubbles are entirely eliminated from the insulation."

Rectifier Voltage Control

BY D. C. PRINCE[1]
Fellow, A. I. E. E.

Synopsis.—*Lack of voltage control is one of the objections which have been made to the use of rectifiers. The author describes a method of voltage control for rectifiers based on the use of a saturated core interphase transformer. Saturation of this device produces a gradual change from two three-phase rectifiers operating in parallel to one six-phase rectifier which has a higher inherent voltage ratio. The theory of operation is discussed and supporting oscillograms and observed regulation curves are shown.*

A RECTIFIER is a kind of electric valve which allows current to flow from an alternating supply into a d-c. load circuit. The instantaneous alternating voltage varies all the way from $\sqrt{2}$, the effective value in one direction, to the same amount in the other direction. There is, therefore, nothing startling in the idea that any voltage between these limits can be communicated to the load circuit. The problem is rather one of practicability than of possibility.

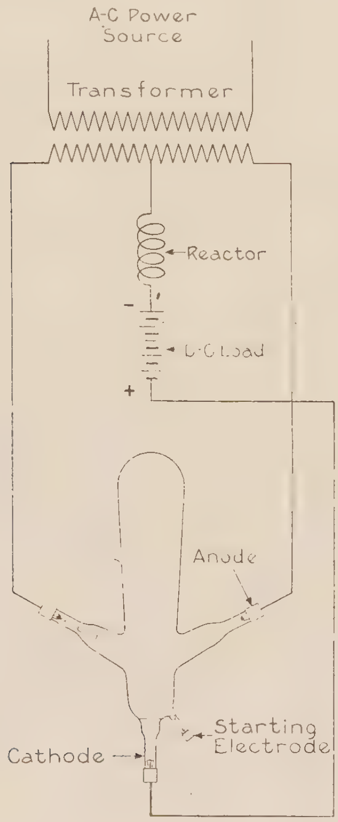

FIG. 1

The voltage communicated to the load circuit is not an instantaneous, alternating value but is an average over a considerable part of a cycle. Consider a simple, single-phase rectifier as shown diagrammatically in Fig. 1. The corresponding wave diagram is shown in Fig. 2. Current flows from the most positive anode to the cathode so that the cathode potential is below the most positive anode only by the amount of the arc drop which is practically constant and relatively negligible in rectifiers having any considerable output voltage.

This diagram assumes no inductance in the transformer or primary supply. The cathode traverses the series of positive lobes of two sine waves displaced 180 electrical deg. This potential is impressed upon the load and d-c. reactor. The counter e. m. f. load chosen will offer no impedance to the alternating components of the irregular cathode voltage. The inductance will offer no impedance to the d-c. component. The voltage wave is thus resolved into its components. The direct component is the average of voltage for a series of half cycles in one direction

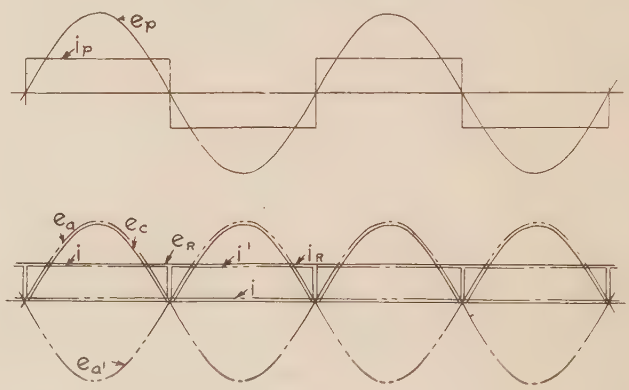

FIG. 2

and is the same as the average of one-half cycle. Its value is $\frac{2\sqrt{2}\,E}{\pi}$ where E is the effective secondary voltage to neutral.

If there were more phases, each anode would be the most positive for a shorter time and so the average voltage impressed on the load circuit would have to be taken for a shorter time. Fig. 3 shows some of the secondaries of a p-phase rectifier. The direction of each coil is the phase vector direction for that phase. For p phases, each anode will be most positive for the fraction of a cycle $\frac{2\pi}{p}$, that is, beginning at an angle $\frac{\pi}{p}$ before the maximum and ending $\frac{\pi}{p}$ after the maximum. The developed voltage wave is shown in Fig. 4.

1. Research Laboratory, General Electric Co., Schenectady, N. Y.

Presented at the Regional Meeting of District No. 1 of the A. I. E. E., Niagara Falls, N. Y., May 26-28, 1926.

The average voltage, G, is found most easily by integrating the wave, that is; finding its area divided by the base.

$$G = \sqrt{2}\, E \times \frac{p}{2\,\pi} \int_{-\frac{\pi}{p}}^{+\frac{\pi}{p}} \cos\theta \, d\,\theta$$

$$= \frac{\sqrt{2}\, E\, p}{2\,\pi} \left[\sin\theta\right]_{-\frac{\pi}{p}}^{+\frac{\pi}{p}} = \sqrt{2}\, E \frac{p}{\pi} \sin\frac{\pi}{p} \quad (1)$$

For various numbers of phases, this equation gives the series of values in Table I. It is seen at once that

TABLE I

p	2	3	4	6	∞
G/E	0.90	1.17	1.27	1.35	1.41

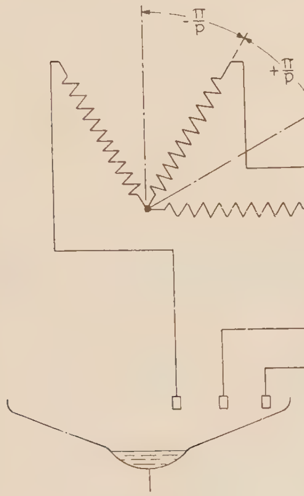

FIG. 3

by increasing the number of phases there results an increase in the average voltage. This indicates how voltage control may be approached. A method of changing smoothly the number of phases from two to

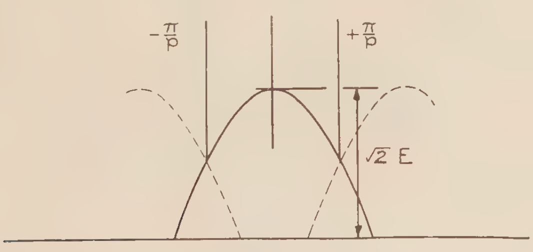

FIG. 4

six would give an increase of fifty per cent in the output voltage.

Two three-phase rectifiers may be connected to a three-phase supply as shown in Fig. 5. These rectifiers have separate inductances in series with their cathodes but feed a common load. Since the two inductances absorb the pulsating components of the voltages of their respective rectifiers, there is nothing to prevent their feeding the load in parallel, each supplying one-half of the current all the time. If the switch S be closed, this condition is changed. There is no longer any impedance to prevent a current shift from one rectifier to the other. Current will naturally flow from the anode with the highest voltage, regardless of its location in a particular rectifier, so that six-phase operation replaces three-phase.

Fig. 6 is a wave diagram of the change. With the

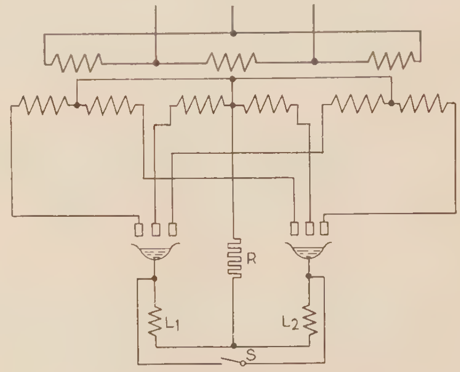

FIG. 5

switch open, the two cathodes have potentials e_1, e_2 averaging e_a. With the switche S closed, the two cathodes follow the potential of the most positive anode, giving the wave e_6 shown by the heavy line.

Instead of the abrupt change from two three-phase rectifiers, the transition might have been made gradually. The two inductances L_1, L_2 may be so interwound that they present large impedance to current changes between rectifiers but low impedance to changes of the total current. The load voltage will then be the average

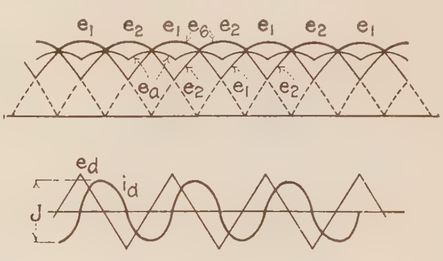

FIG. 6

e_a of the rectifier voltages, but only so long as both are carrying current. Should one stop carrying current, it could no longer influence the average voltage, for both windings of the choke system must carry a variable current in order to supply the inductive drops necessary for the voltage equalizing action.

The inductances, L_1 L_2, are not infinite, so that the tendency of the rectifier having higher voltage to take current from the other will cause a circulating current between the two rectifiers. In Fig. 6, e_d is the difference in voltage, i_d the circulating current. As long as this circulating current is less than the load current supplied by either rectifier, there can always be sufficient current changes to set up the difference voltage and preserve the average. If, however, the interchange

current becomes equal to the load of one rectifier, one will momentarily be carrying all the current, and the voltage will no longer be the average, but will be the voltage of the higher rectifier.

With a further increase in interchange current, there will be a longer period during which there is no drop across the inductances $L_1 L_2$ and the output potential will follow the higher rectifier for a longer time. Fig. 7 shows the waves under this condition. A value of difference current has been used which has an amplitude equal to the entire rectified current, J. With this

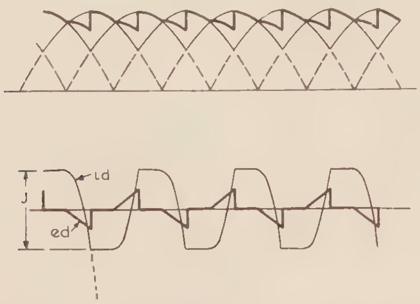

Fig. 7

value, the load current is divided between the two rectifiers half the time and carried by one for half the time. To maintain the difference voltage, the difference current would have had to continue as shown by the dotted extension, but this it could not do because the current from one rectifier could not drop below zero.

Saturation forms a ready means of altering the interchange current as desired. Fig. 8 is a diagrammatic representation of a saturation regulator adapted

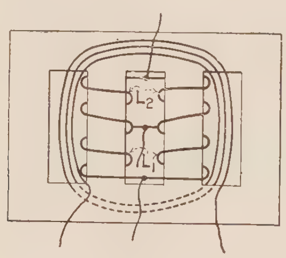

Fig. 8

for this use. It consists of a four-legged core on which two sets of windings are placed. One winding consists of two circuits surrounding the two central legs individually and connected so that the upper and lower halves of each will function as L_2 and L_1, respectively. The flux required for the difference voltage circulates in these two central legs and does not traverse the other two. The second winding used to saturate the core surrounds both central legs. The flux linkages are thus so balanced that current changes in either winding will induce no voltages in the other.

To increase the interchange current which is the exciting current in the central windings a direct current is passed through the outer winding. The flux produced by this current passes in one direction through the central legs and returns through the outer legs. It, therefore, saturates the central legs which carry the alternating flux, and this saturation increases the interchange current and thereby the output voltage.

The direct current required to saturate the core may be obtained from the rectifier output in which case a

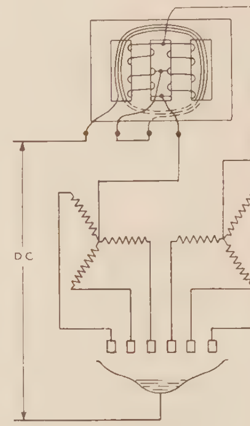

Fig. 9

compound rectifier results, or it may be obtained from a separate source controlled through a voltage regulator. The complete circuit diagram for compounding on load is shown in Fig. 9.

If rectifier transformers and supply lines had no inherent regulation, it would always be possible to secure the increases shown in Table I by changing the equivalent number of phases. There is, however, a considerable amount of regulation in the transformer which tends to be greater with increased numbers of equivalent phases. Take the case of the three-phase rectifier shown diagrammatically in Fig. 10, having all the inductance X concentrated in the anode leads and an infinite choke L to keep the total current constant.

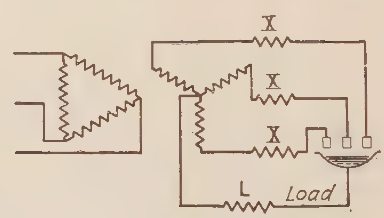

Fig. 10

When the voltages of a_1 and a_2 pass through equality, current will begin to change from a_1 to a_2. While the change is taking place the two anodes are at the same potential since otherwise they would not divide the current. The voltage difference between the two phases is absorbed in the inductances X. The current and voltage appear as shown in Fig. 11.

The rate at which current transfer will take place is proportional to the voltage causing the transfer, which is the vector difference between the phase voltages. At each transfer some of the average voltage

is lost as shown by the crosshatched areas in Fig. 11. The curve of current transfer is a sine wave which lags 90 deg. behind the phase-voltage difference because the drop is inductive. At any instant the value of the rising current to one anode is independent of load because no current change takes place in the load circuit. When all the current has transferred in angle u the

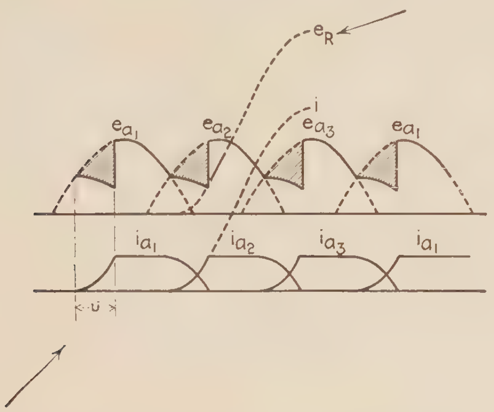

FIG. 11

change ceases. The greater the load, the greater will be the angle u.

It appears from Fig. 12 that the general expression for the phase-difference voltage is

$$\frac{e_d}{2} = \sqrt{2}\,E \sin\frac{\pi}{p} \tag{2}$$

This voltage produces a current

$$i = \frac{\sqrt{2}\ E\ \sin\dfrac{\pi}{p}}{X}\,(1 - \cos\theta)$$

At the end of the lap angle u, the load of direct-current J is reached so that

$$J = \frac{\sqrt{2}\,E}{X}\,\sin\frac{\pi}{p}\,(1 - \cos u) \tag{3}$$

The curve of instantaneous lost voltage is the same

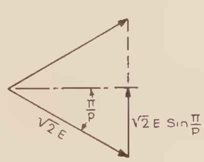

FIG. 12

as the half difference voltage used in making the current transfer. The average loss in output voltage represented by the hatched area is the wave e_R which has the same phase as the current i. Its value is

$$e_R = \frac{p}{2\,\pi}\int_0^u \sqrt{2}\,E \sin\frac{\pi}{p}\sin\theta\, d\,\theta$$

$$= \frac{p}{2\,\pi}\sqrt{2}\,E\sin\frac{\pi}{p}\,(1 - \cos u) \tag{4}$$

The open-circuit voltage has already been found to be

$$G_0 = \sqrt{2}\,E\,\frac{p}{\pi}\sin\frac{\pi}{p} \tag{1'}$$

so that the voltage under load is

$$G = G_0 - e_R$$

$$= \sqrt{2}\,E\,\frac{p}{\pi}\sin\frac{\pi}{p}\left(1 - \frac{1-\cos u}{2}\right)$$

$$= G_0\left(1 - \frac{1-\cos u}{2}\right)$$

Equation (3) connecting J and $(1 - \cos u)$ can be used to replace the latter by the former. This results in

$$G = G_0\left(1 - \frac{J\,X}{2\,\sqrt{2}\,E\sin\dfrac{\pi}{p}}\right) \tag{5}$$

It would be advantageous to arrange this equation so that the performance of the device might be compared with that of more familiar apparatus. Let it be assumed that there will be a four per cent drop in the transformer when carrying an ordinary sine wave a-c. load equal to its rating for use with a rectifier. Then the short-circuit current per phase is $\dfrac{E}{X}$ or $25\dfrac{W}{p\,E}$ where W is the rated output of the rectifier. Equating these two values and solving for X gives

$$X = \frac{p\,E^2}{25\,W}$$

and the output voltage equation may now be written

$$G = G_0\left(1 - \frac{J\,p\,E}{50\,\sqrt{2}\,W\sin\dfrac{\pi}{p}}\right) \tag{6}$$

or making use of equation (1′)

$$G = G_0\left(1 - \frac{\pi\,J\,G_0}{100\ W\ \sin^2\dfrac{\pi}{p}}\right) \tag{7}$$

In the derivation of these equations it was assumed that all the reactance was in the secondary windings of the transformer with no mutual reactance. This is convenient and gives results of the right nature. The magnitude of the results may be wrong, however, for, unless all of the leakage reactance is actually located in the manner represented in Fig. 10, the inductance of the paths taken by the commutating currents may be appreciably less than the value obtained by considering short-circuit conditions in the transformer. This is due to the fact that in the latter case the currents have a mutual reaction which can greatly increase the apparent reactance.

The commutating currents on the other hand usually are not required to flow through circuits with much coupling between sections. No advantage of this kind occurs in the single-phase rectifier, but in the three-phase case, the reactance presented to the commutating currents is approximately half that determined by short-circuit measurements. The advantage in the six-phase case is hard to determine exactly. If the transformer

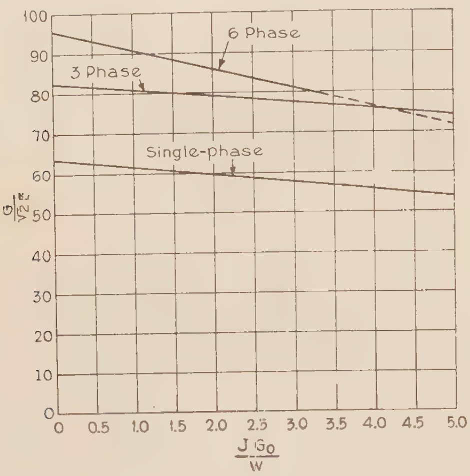

Fig. 13

has a primary and tertiary winding and all the reactance is in the primary, the advantage may be as high as six to one, but as a conservative estimate, let it be assumed that the reactance will be 40 per cent of the value determined from the simple measurements.

Fig. 13 indicates the regulation curves given by equation (7) and takes into account the corrections just described. The regulation curve for the compound rectifier will fall between the curves for the six-phase and three-phase rectifiers. By increasing the saturation of the interphase transformer as the load is increased, it may be made to give high reactance at low loads and small reactance at heavy loads. As a result the output voltage will approach that of a six-phase rectifier under heavy loads and will be nearer to that of a three-phase rectifier under light loads. It will be seen that the range of voltage available for compounding is somewhat limited if only the three and six-phase circuits are used. It is probable, however, that the limits are sufficiently wide for the great majority of applications. A much larger variation can be obtained by going from the single-phase to the six-phase connection. This transition is entirely practical but uses slightly more material than the three-phase to six-phase case and is therefore not desirable as long as the latter arrangement can be made to give the required characteristics.

Under extremely light loads, the direct current through the interphase transformer will be so small that it would be impractical to supply a transformer having sufficient exciting reactance so that its exciting current would always be smaller than the load current. Therefore, the effect of the interphase transformer will be lost as zero load is approached and the no-load voltage will be that corresponding to six-phase operation.

As long as the instantaneous current in the interphase transformer does not fall to zero, its reactance does not appear in the a-c. circuits. As soon as the current in one branch of the interphase transformer is actually interrupted, however, this transformer acts just as though it were inserted in the anode leads. Fig. 14 shows the circuit through which the transient current flows which accomplishes the commutation of the output current between anodes. The exciting inductance of the interphase transformer is added to the leakage reactance of the windings of the main transformer to obtain the value of X used in calculating the regulation curve. The result will therefore be a six-phase regulation curve dropping much more rapidly than that corresponding to the main transformer alone and the rapidity with which the voltage decreases will be dependent upon the exciting reactance of the interphase transformer.

After sufficient load current is flowing so that the interphase transformer is carrying current continuously, the output voltage will be that corresponding to the three-phase rectifier. As more load is applied the output current flowing through the saturating winding of the interphase transformer will decrease the reactance of the main circuit. The exciting current will then rise until it is as large as the load current and continuous choke action will be lost. The voltage will then be displaced from the three-phase value in the direction of the potential corresponding to six-phase operation. By this means the voltage may be held constant over the greater part of the load range or may even be made to increase slightly with load.

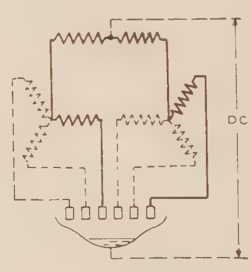

Fig. 14

In Fig. 13 part of the curve for six-phase operation is shown dotted. In this range the voltage is no longer given by equation (7) because the load is so great that three anodes carry current simultaneously during part of the time. Due to lack of complete data on the reactance of the circuits traversed by the commutating currents, it is not worth while to calculate the voltage under these circumstances. The three-phase rectifier curve will have a similar limit of applicability, but this limit is not reached in the range shown in Fig. 13.

Figs. 15, 16, 17 and 18 indicate the results of experimental work which serves as a check on the theory of

operation of rectifiers with compounding. Fig 15 shows the wave shapes obtained with an oscillograph when an experimental rectifier was operating as two separate three-phase units connected in parallel through an un-

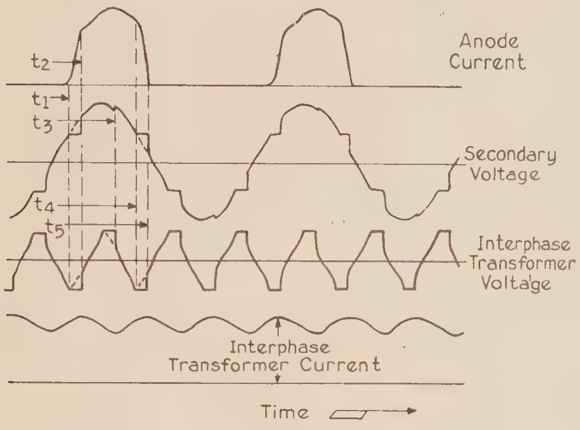

Fig. 15

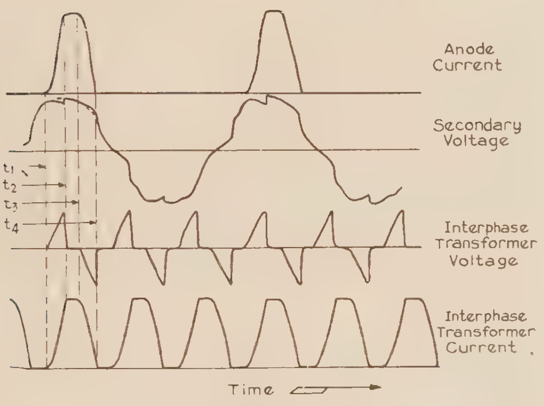

Fig. 16

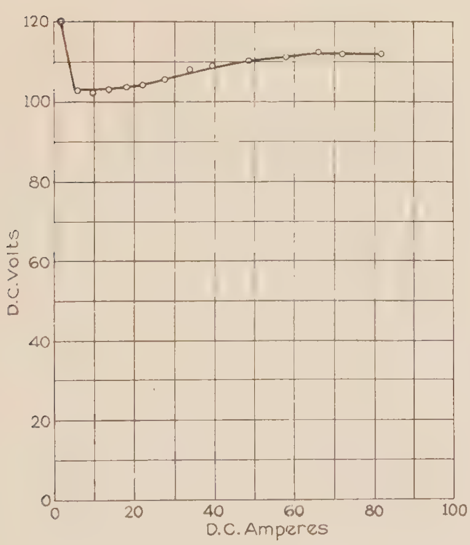

Fig. 17

saturated interphase transformer. At time, t_1, the secondary voltage of the phase being measured became equal to that of the preceding phase in the same three-phase group, and it began to conduct current. Between t_1 and t_2 both phases were conducting current and the reactive drops caused by the changing currents averaged the induced voltages of the two phases so that their terminal voltages were nearly constant. At time, t_2, the current transfer was completed and the terminal

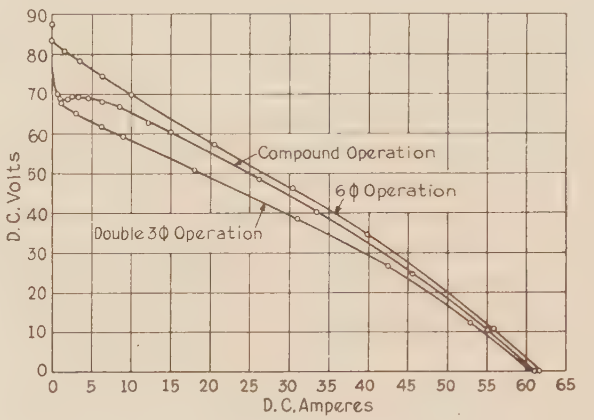

Fig. 18

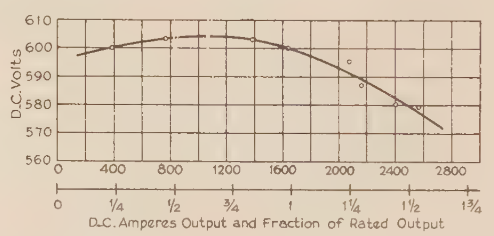

Fig. 19

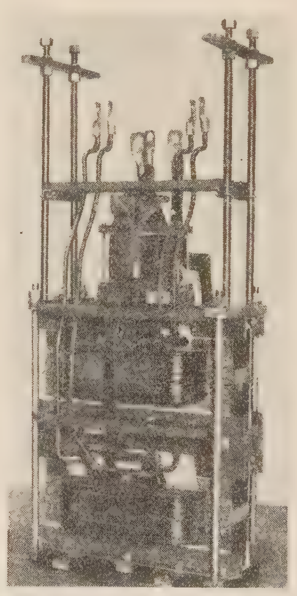

Fig. 20—Interphase Transformers

The 180-cycle units are provided with series d-c. saturating coils and variable gap in the d-c. core circuit.

voltage of the incoming phase again became equal to its induced voltage. Between t_4 and t_5, the current left the phase under observation, and this time the reactive drop prevented the terminal voltage of the phase from falling as rapidly as the induced voltage until after the

transfer was completed. The dotted lines indicate the form of the secondary voltage and interphase transformer voltage waves, if they had not been distorted by the reactive voltages during current transfer. The slight irregularity in the secondary voltage wave at time t_3 was caused by commutation of currents in the second three-phase group of windings and was present because of the coupling between the two groups through the transformer primary windings.

Fig. 16 shows the wave shapes obtained with the core of the interphase transformer saturated. The operation is now that of a six-phase rectifier. Current is building up in the phase under observation between t_1 and t_2 and decreasing between t_3 and t_4. Not more than two anodes carry current simultaneously, and between t_2 and t_3 only one anode is conducting. The interphase transformer now carries pulses of current of the same shape as the anode pulses, but, since it carries the current of all the anodes, the pulses will be closer together. There is a voltage across the interphase transformer only during the time the current is transferring between anodes, which transfer must occur through it. As the reactance of the interphase transformer influences the period of commutation, it is apparent that the output voltage can never rise to the six-phase voltage corresponding to the transformer by itself. Instead, the output voltage will approach this value as the reactance of the choke is decreased by saturating it more and more, but can never reach it.

Fig. 17 shows an experimental compounding curve obtained from a small rectifier. After the first sudden drop to the normal three-phase voltage at six amperes, the voltage rises steadily with increase in load to 70 amperes, after which it again falls. To obtain this curve no changes were made other than changes in load. This rectifier had insufficient capacity to stand loading to short circuit. Accordingly, additional reactance was added enabling the curve of Fig. 18 to be taken. In Fig. 18 the load is increased to short circuit under three conditions, with no saturation of the interphase transformer, with the compounding apparatus in operation, and with the interphase transformer short-circuited. Although the compound curve never equals the six-phase curve except at short circuit, the six-phase voltage is approached sufficiently to give flat compounding from light load to 6½ amperes which is 10 per cent of the current under short circuit.

Tests which have been made on the performance of a 1000-kw., 600-volt, 12-phase rectifier further substantiate the correctness of the theories herein set forth. Fig. 19 is a regulation curve obtained with this rectifier adjusted to give substantially flat compounding out to full load, 1667 amperes. Fig. 20 is a photograph of the interphase transformer. Since the set is twelve-phase, there are three interphase units. The two lower units combine each two groups of three phases and have direct current saturating windings. The small top unit combines the two six phase groups into one twelve-phase unit.

Polarization of Radio Waves

BY E. F. W. ALEXANDERSON[1]

Fellow, A. I. E. E.

UNTIL rather recently, the practise of radio communication was confined to the use of long, earth-bound waves. These waves are preferred on account of the regularity of day and night operation and the absence of fading. The characteristics of the earth-bound wave were extensively explored and there was a tendency to generalize these results assuming that they apply to all radio wave transmission.

Usually the earth-bound wave is thought of as a moving electromagnetic field with horizontal magnetic lines sweeping parallel to the earth and vertical electrostatic lines terminating in the conducting earth. This theory has been supported by a great deal of practical evidence. Attempts to measure horizontally electrostatic lines have always given negative results and it almost seemed obvious that this should be so. It, therefore, seemed quite unnecessary to speak of polarization of radio waves, since the waves were supposedly always vertically polarized due to their nature of being earth-bound.

A great amount of data was collected and among these were some surprising observations. For instance, it seemed as if the wave did not always come in from the proper direction but wandered around, seeming to come at times from the side and sometimes even from behind. This led to a good deal of discussion, but no plausible explanation was found. Yet the evidence was accepted as incontrovertible that such direction changes did exist because the observations were confirmed by so many competent observers.

Recent investigations of the phenomena of radio wave propagation, however, have led to another explanation, the conclusion being that the observed irregularities were not actually changes in direction but changes in the plane of polarization. Whether such an explanation had been considered at some earlier date the author does not know, but if it was tentatively advanced, it was undoubtedly discarded on the ground of the experimental evidence, showing that the horizontal electrical lines did not exist. As a matter of fact the

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polarization theory did not originate with the study of long-wave phenomena and it requires a new conception of wave propagation, developed through recent work on short waves.

Observations on Short Waves

Our first experience in signaling with horizontally polarized waves was gained as a result of an incident in an investigation which had been organized to study directive radiation with short waves. One of the several directive antenna systems which were used was a combination of two large, square, vertical loops, tuned for a wavelength of 50 m. Each loop consisted of eight sections of conductor, separated by eight condensers so that each section was independently tuned. The composite antenna thus had four vertical conductors, two in each loop, and the object of the test was to regulate the direction and phase of the currents so that the composite antenna would give a unidirectional radiation in the plane of the loops. The only practical way to adjust the phase of the currents proved to be to make measurements of the composite radiation within a few hundred feet of the antenna. When the radiation diagram so obtained was in agreement with the theoretical expectations, it was assumed that the system was properly tuned. The experimental station at Schenectady was in radio communication with the stations of the Radio Corporation of America, at Riverhead, Long Island, and Belfast, Maine, where the signals were measured to ascertain whether the directive characteristics were the same at distant points as near the station. In one case it was found that no radiation whatever could be observed in the field around the station. But investigation showed that, by accident, one of the loops had been reversed so that while current was flowing in all the vertical conductors as indicated by the ammeters, the resultant effect in radiation was zero. No sooner had these facts been ascertained than a communication was received from Long Island that the signals were 50 per cent stronger than in previous tests. In view of the absence of any radiation near the station this surprising result called for further analysis. It was thus found that while the currents in the vertical conductors were in such a direction as to neutralize each other, the two top conductors carried current in the same direction. These conductors being horizontal, it followed that the radiation must have been horizontally polarized and that the failure of the local instrument to indicate any radiation was due to the fact that it was sensitive only to vertical radiation.

Since then, a number of antenna forms for horizontally polarized radiation have been tested and used in commercial service by the Radio Corporation of America. The practical conclusion reached through these tests, as well as the findings of the government laboratories and many amateurs, is that in most cases horizontal transmission and reception with short waves is superior to the old methods of using vertical polarization.

When one attempts to discuss the phenomena of wave polarization, he finds many theoretical and practical aspects and many questions which may be asked. For instance:

How does the wave acquire a horizontal polarization when it is radiated vertically and why does the wave become vertical when it is radiated horizontally?

Does the wave always twist in space or only under some circumstances, and what are these circumstances?

Why is horizontal polarization the rule on short waves and so difficult to discover on long waves?

How strong is static in the horizontal plane?

What relation has polarization to fading?

Does a wave fade in the horizontal and the vertical plane at the same time?

Can direction finders be made to compensate for errors due to polarization?

Many such questions may be asked and only a few can be answered definitely. If the idea of wave polarization is to be more than an empty phrase, we must try to form in our minds a picture of what the wave itself consists before we can intelligently discuss the peculiarities of its behavior.

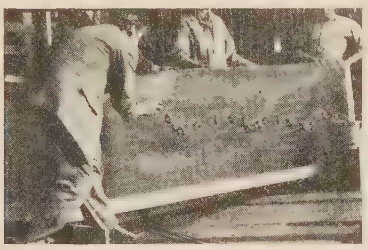
Theory of Wave Motion

This subject is being approached from two angles: One, the classical theory of light radiation in the ether; the other, the electromagnetic theory as we know it in electrical engineering. Both of these theories have their difficulties. The only positive knowledge we have of electricity is the electronic theory. We know that the electron is the smallest element of matter. We know its mass, its electric charge and how fast it travels. But we do not know what magnetism is. As a matter of fact there is good reason to believe that there is no distinct force that can be called a magnetic field. Modern science also denies the existence of ether. We have tentatively substituted a conception of electromagnetic field, in which the energy appears sometimes in electric form and at other times in magnetic form. This is a mathematical rather than a physical substitution, but it is convenient because it permits us to use the equations for the electric and magnetic fields as used in electrical engineering. However, it is not an explanation. To an electrical engineer, a magnetic field is very real and in its nature is quite different from an electrostatic field. From this point of view, it requires a good deal of imagination to conceive that a magnetic field is nothing but a manifestation of a moving electrostatic field. Yet we may be forced to change our conception to that extent. This means the return to Faraday's idea of tubes of force which are material bodies with mass and elasticity.

The ordinary antenna consists of a vertical wire in which electrons periodically move up and down, and the space field, which accompanies the electrons, moves up and down with them. This moving space field is a physical reality. It has a mass and kinetic energy

stored in its motion and it has elasticity. A physical model of such a field can be built. The field itself extends into space but the different portions of the field do not move simultaneously. This elastic, electric body moves in the only way in which one may conceive of a structure maintaining a periodic motion, that is, in waves proceeding from the center. The magnetic field is nothing but the kinetic energy of this moving structure. The electromotive forces which, according to our well-known equations, are induced by the change in the magnetic field, are nothing but the elastic forces which react against the inertia of this electrical body.

With this picture in mind, it is not difficult to see the physical meaning of wave polarization. The ordinary radiator has a vertical conductor in which the electrons move up and down and the accompanying fields move up and down with them within a radius of one-quarter wave length. The inertia of this moving field, close to the conductor, is propagated through an elastic medium in accordance with ordinary laws of wave motion. In the wave which thus proceeds from the origin, every element oscillates in a vertical plane.



Mechanical Model Showing How a Plane Wave Changes Into a Spiral

Thus the vertically polarized radiation is closely analogous to a wave on the surface of water.

The radiator of horizontally polarized waves consists of a closed loop conductor in the horizontal plane. In this conductor the electrons circulate first in one direction and then in the other.

Mechanical Model for Studying Wave Polarization

A mechanical model has been built for the study of wave polarization in the laboratory. The model consists of weights suspended in such a way as to make them free to move in all directions. Twenty-two of these weights are arranged in a row and connected by rubber bands. Each weight is suspended from a yoke and an equal weight hung on the other side of the yoke to serve as a counter weight. A screen is set up so as to hide the counterweights and avoid confusion in observing the wave motion. This model was set up especially to study the twisting of the plane of polarization and the experiment has strikingly confirmed the theory which it was intended to illustrate. This theory is briefly as follows:

Let us assume that the medium through which the radio waves pass has such characteristics that the velocity of propagation for a vertically polarized wave differs slightly from the velocity of the propagation for a horizontally polarized wave. For the present purpose, it is not necessary to try to explain the reason for this difference in velocity, but we may assume that the reason for it is the electrostatic or magnetic earth field or a retarding effect due to the closeness of the earth. Whatever the cause, we may assume that such a difference of velocity exists and the mechanical model has been constructed so as to reproduce such conditions. Thus wave motions in the horizontal or vertical planes can be studied independently, and these two wave motions may be adjusted for different velocities. A wave started in the vertical plane maintains itself vertically and a wave started horizontally maintains itself horizontally. If, however, a wave is started in a plane 45 deg. between the vertical and the horizontal, it is found that the wave motion proceeding therefrom assumes the shape of a spiral. The straight-line oscillation of the first weight is passed along as an elliptical motion which gradually widens into a circle. Then this circle again narrows down to an ellipse and finally to a straight line at right angles to the original line of oscillation. This is exactly in accordance with the theory. The point where the wave has shifted its plane of polarization 90 deg. is the point at which the faster of the two waves is half a wave length ahead of the slower wave. From this point on, the wave proceeds, repeating this peculiar spiral motion.

The fact that the twisting of the wave is due to different velocities in the two planes of polarization can also be demonstrated by this model. For such a purpose, the tension of the rubber bands between the counter weights is changed. The effect of this is to change the velocity of propagation in the vertical plane, whereas the velocity in the horizontal plane has not been affected because only the vertical motion is transmitted to the counter weights by the suspension yokes. The system can thus be adjusted so that the velocities in the horizontal and the vertical planes are exactly equal. After this has been done, it is found that the tendency to spiral motion disappears and the wave remains strictly in the plane in which it has been started.

While this mechanical experiment brings out no new facts unknown to the classical theory of wave motion, it helps us to visualize the main phenomena in the radio wave propagation which we are trying to explain. The phenomenon of a constantly shifting plane of polarization, discovered experimentally in the tests between Schenectady and Long Island, can thus easily be explained.

This conception of the wave motion also is a help in explaining the phenomenon of fading. There is much experimental evidence that fading is a phenomenon of wave interference. In other words, the fading is due to the fact that the radio waves arrive at a certain point through two paths. The waves will sometimes add to each other and sometimes neutralize one another. If

one bears in mind the observations on the mechanical model and the fact that the waves in the two planes can be traced through, separately and distinctly, one may conclude that the two paths of the radio wave which produce fading are not necessarily two separate physical paths but may be the two paths in the horizontal and the vertical plane of polarization. For further illustration of this, a detector may be introduced into the mechanical model. If this detector is placed at a certain distance from the origin it is found that it gives no response when the system is adjusted for different velocities of propagation, whereas when the system is adjusted for equal velocity in the horizontal and vertical plane it gives a maximum response. Thus the phenomenon of fading has been reproduced mechanically through polarization in a single wave path.

By this, it is not suggested that in actual radio transmission the mechanical equivalent is sufficient to explain the fading. However, it is offered for what it may be worth as a help to interpret the many observations in actual radio transmission which are being accumulated.

Irregularities of Direction Finders

It has been known almost since the beginning of transatlantic communication with long waves that measurements of direction of wave propagation with rotating loops show peculiar irregularities from the time of sunset. It has also been known among aviators that direction finder bearings on an airplane are correct only if the plane flies in the line towards the observing station. If the plane flies at right angles, the direction finder gives false orientation as high as 45 deg. or more. This false orientation is greater if the antenna is trailing horizontally. It is therefore attempted to keep the

Transmitting Loops Used in Tests which Revealed Horizontally Polarized Radiation

antenna as nearly vertical as possible by a weight.

A third set of observations has been brought out through the research work in Schenectady on horizontally polarized waves radiated by horizontal loop. Measurements with a direction finder receiver usually give bearings approximately at right angles to the place where the station really is, but sometimes it gives no direction indication at all. Other measurements indicate that the direction of wave propagation is almost perpendicularly vertical. The observation that the wave appears to come straight down from above suggested an explanation that wave components radiated directly upwards had been reflected straight down by the Kennelly-Heaviside layer. However, in view of the other facts to be considered this explanation seems less likely.

Putting all these facts together it seems now that the old observations on the long wave, the airplane, and our recent work on the horizontal loop all may be explained as a characteristic behavior of the horizontally polarized wave. In all three cases, while the wave appears to come in from unexpected directions, it actually does not. When in the third case there is no direction indication whatever, and the wave appears to come in from above, this also is an illusion. The question is, what really does happen?

Transmitting Antenna for Horizontally Polarized Waves and Receiving Instrument Indicating Apparent Wave Direction at Right Angles to True Direction of Propagation

This is the problem on which the experiment with the mechanical model can throw some light. For this purpose let us return to the idea that the radio wave is a mechanical wave motion in the elastic electric medium. In the mechanical model, the weights represent the mass and the rubber bands the elasticity of this medium and the vertical as well as horizontally polarized wave can easily be reproduced. But in order to imitate a wave motion over the surface of the earth, one must also in some way imitate the presence of the earth. The earth is a conductor and therefore the elastic strains represented by the rubber bands cannot exist in the earth. On the other hand, displacement currents in the electric medium can induce conduction currents in the earth. These conduction currents are electrons in motion which can be represented by weights not tied together by rubber bands in the horizontal plane, whereas they are electrically associated with the electric medium above. To imitate this condition, weights may be hung by vertical rubber bands so that they are elastically associated with the wave medium but not connected to each other. If, now, a horizontally polarized wave is sent forth through this system, it is found that the wave motion is propagated to the vertically suspended weights producing elastic strains in the vertical rubber bands. It must be remembered

that the elastic strains represent electromotive forces and these elastic strains so produced are of the same character as if they were a part of a vertically propagated wave motion. No such wave motion actually exists and these strains are only the electromotive forces which induce currents in the ground. If we now assume that a receiving antenna is set up in the form of a vertical loop with its plane at right angles to the wave motion, the primary wave motion does not induce any currents in the loop. However, the secondary electromotive forces, which induce currents in the ground, are in the plane of this loop and tend to induce such currents in the loop. In other words we may say that,

EXPLORING ANTENNAS

inasmuch as the currents induced in the ground are at right angles to the wave motion, the loop is in the plane of those ground currents which, in their turn, induce currents in the loop.

If this theory is correct, it should be found that false indications of the direction finder and the apparently vertical wave propagation can be observed only in the proximity of the ground. Thus, if observations are made in airplanes high enough from the ground, the horizontally polarized wave should show a horizontal plane of polarization with a true direction of propagation.

Some measurements have been made which confirm these conclusions. By making frequent measurements to within ten miles of the station a set of tests was made exploring the characteristics of a wave radiated from a horizontal loop. The composite picture which was obtained from this test was a continuously twisting plane of polarization with alternate points of plane and circular polarization. At intermediate points, the polarization was elliptical. The plane polarization was indicated by sharp directional bearings and circular polarization was indicated by equal intensity from all directions. The observations indicating plane polarization gave bearings sometimes towards the transmitting station and sometimes at right angles.

Beside these measurements around the vertical axis, observations were made with the loop in the horizontal plane. On flat fields the horizontal position gave nearly zero response. At the top of a steep hill and a high bridge, the response in the horizontal plane was equal to the vertical.

These results indicate the presence of a horizontal and a vertical wave component with different velocity of propagation. Whenever the two waves are in phase, they give plane polarization. When they are 90 deg. out of phase, they give circular polarization. The observation with the loop in the horizontal position on the top of the hill and the bridge shows that even a moderate elevation is sufficient with short waves to reach the point at which the horizontal electromotive forces are not short circuited by the ground.

All this leads the author to believe that horizontal polarization is not confined to short waves only. Direct observation of horizontal polarization at long waves could be made only at great heights but indirect observations through the effect of ground currents can be made by ordinary direction finders at any wave length. If this theory is correct it means that the irregularities of direction finder indications recorded on long waves can be explained by the presence of horizontally-polarized wave components.

JORDAN RIVER TO PRODUCE ELECTRICITY TO REVIVE PALESTINE

The waters of the Jordan River, in Palestine, once were regarded as having power to revive the souls and spirits of men; today the river is helping to revive industry in the Holy Lands. Bernard Flexner, president of the Palestine Economic Corporation, has announced that the new corporation will help finance the hydroelectric station on the Jordan which will supplement the electric power produced by oil-engine driven generators at the ancient towns of Tel Aviv, Haifa and Tiberias.

The hydroelectric plant will be connected by transmission lines with the lines from the oil-engine stations to establish the beginning of a power system that some day may serve the whole of the Holy Lands. Factories there are now operated by electric power and the use of electric appliances in the homes is becoming more and more common.

TREMENDOUS WASTES DUE TO BAD LIGHT

The bugaboo of bad light in schools and factories is no imagination, according to Guy A. Henry of New York, general director of the Eyesight Conservation Council of America. Speaking at Boston May 28 he stated that one-third of the six million retarded pupils in American schools were in their present condition because of neglected eyesight that could be partially corrected by proper illumination. Factory waste chargeable to poor lighting, he declared, totals thirty million dollars of industrial waste and industrial accidents due to poor lighting cause an annual loss of 300 million dollars.

Abridgment of

Lightning and Other Experiences with 132-Kv.-Steel Tower Transmission Lines, and its Bearing on Tower-Line Design from the Continuity of Service Standpoint

BY M. L. SINDEBAND* and P. SPORN*

Member, A. I. E. E. Associate, A. I. E. E.

Synopsis.—*A large number of transmission lines have been erected without adequate consideration having been given to the ability of the line to stay in circuit electrically during the occurrence of lightning or other disturbance conditions. These come, however, within the range of the transmission engineer's field of action.*

The author's experience with a 55-mi., 132-kv. transmission line since 1917 to date is cited, the particular line being one which has been very successful from a standpoint of continuity of service. Further experience with other lines built with variations on the original design and placed in service in 1924 and 1925 is given. A detailed analysis is given of eighty-eight cases of lightning trouble on one of these lines during 1925, the various steps taken to reduce the frequency of this trouble, the effect of increased clearances and separations, of additional insulators, of flux control units, and of arcing horns and shields on the amount of trouble and on the damage to insulator and conductor are discussed both from the standpoint of actual experience and from the laboratory analyses and investigations made.

A general discussion of the ground wire and its effect on lightning voltages is given and the arguments for and against it are discussed. The importance of paying attention to the mechanical side of the ground wire and the effect of such attention on continuity of service is pointed out.

A summation is given of the analysis and experience of the authors in operation of 132,000-volt lines as applied to transmission line design from the standpoint of continuity of service.

LIGHTNING disturbances, if they are electrostatic disturbances, are, of course, beyond the control of the engineer but the effects of these disturbances on the transmission system are partly within his control and are within his province of action, and any transmission line that is not designed with a view to properly standing up under lightning conditions, has, of course, not been adequately designed. It is an undoubted fact that a good many lines have been designed in the past, and even in the last five years, where the factor of the ability of the line to stay in circuit under lightning disturbances has not been adequately taken into consideration and it has taken actual operating experience to disclose that fact.

132-Kv. Lines Considered

The author's first extensive experience with a 132-kv. line was with the 55-mi. transmission line built on double-circuit steel towers and running from the Windsor Power Plant of the Ohio Power Company and of the West Penn Power Company, located approximately 12 mi. north of Wheeling, W. Va., to Canton, Ohio, the line running in an approximately straight northwestern direction. A sketch of this tower as well as pertinent design data is shown in Fig. 1. This line is equipped with two-ground wires, ⅜ in. diameter Siemens-Martin, and was placed in operation late in 1917. The line is insulated with 10 disk units at suspension points and 12 units at dead-end points. When this line was put into operation there were operating four 30,000-kv-a. steam turbine units at the Windsor Plant and these constituted practically 80 per cent of the capacity connected to the 132-kv. transmission system of which these two lines formed a part. The line has had altogether 41 interruptions due to lightning since it was put into service, and divided by years as follows:

1917	2	1921	4
1918	4	1922	6
1919	3	1923	4
1920	5	1924	6
1925	7		

In 10 per cent of the cases both lines were affected. All but four of these interruptions were such that they did not affect in any way the insulators or the conductor nor did it require any work to repair these. On the four other occasions mentioned the insulator string was flashed and damaged to a point necessitating a change and the conductor dropped to the ground. The ground wire was removed from over all the railroad crossings on the Windsor-Canton line during 1924, the work being completed by the end of August. In 1925, 12 mi. of ground wire were removed at each end of the line, this being done as a precautionary measure. The wire was actually not in very bad condition but atmospheric conditions at both ends of the line were rather bad and there was danger of deterioration developing to a point that would be dangerous. Up till now this wire has not been replaced. It will be noticed from the operating record that the number of interruptions apparently did not in any way increase due to the removal of this ground wire although perhaps a sufficient time has not elapsed for this point to be known definitely. Thus much is known, however; all the trouble encountered in 1925 was on sections where ground wire was installed. It will be noted that in general the history of operation of this line has been a highly successful one, and that the line has given such uniform continuity of service as to make possible the supplying of a load to the City of Canton amounting to well over

*Both of American Gas & Electric Co., 30 Church St., New York, N. Y.

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60,000 kv-a. dependent entirely upon the transmission line for its power.

During 1923 and 1924 the construction of three additional lines in Ohio was undertaken as follows:

1. A 73-mi., double-circuit line from the Philo Plant of the Ohio Power Company, located at Philo, Ohio, on the Muskingum River, south of Zanesville, and running to Canton, Ohio.

2. A 15-mi., single-circuit line, but strung on the same type of towers as the Philo-Canton line, running from Philo to Crooksville, Ohio.

3. A 45-mi., single-circuit line from Fostoria, Ohio, running approximately southwest to Lima, Ohio. This line, too, was to be built on a double-circuit transmission tower with only a single-circuit strung.

During 1924 and 1925 there was again constructed a 129-mi. line of the same type of structure, with only a single-circuit strung but utilizing 397,500-cir. mil., A. C. S. R. instead of 336,400 A. C. S. R. used on the three lines previously mentioned. This line runs from Lima, Ohio, to the Twin Branch, Indiana, plant of the Indiana & Michigan Electric Company which is located on the St. Joseph River, approximately 8 mi. east of the city of South Bend.

The tower utilized on all these lines is shown in

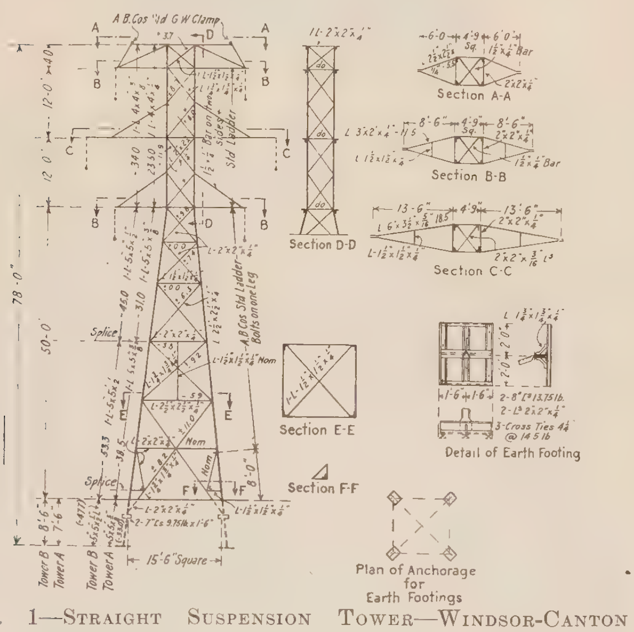

Fig. 1—Straight Suspension Tower—Windsor-Canton Line (1916)

Fig. 2. Comparing Figs. 1 and 2, it will be noticed that a number of changes were made between 1915 when the Windsor-Canton tower was designed and 1922 when the Philo-Canton tower was designed. It will be seen that the height of the bottom crossarm was raised from 50 ft. to 64 ft., the vertical crossarm spacing was raised from 12 ft. to 13 ft. and the height of the upper crossarm was raised from 74 ft. to 90 ft. Further, while the Windsor-Canton tower was designed and erected with two ground wires, the Philo-Canton and other towers were all designed for but one possible ground wire and none was actually installed. A large number of factors brought about this change in the design:

1. In the first place, transmission line construction costs increased greatly between 1917 and 1922. The increase was not only brought about by the increased cost of materials and the higher cost of labor, but also by the increasing cost of right of way. A definite conviction had come about that lines were costing too much and that an attempt should be made to lower the cost, and the most logical and natural suggestion was the lengthening of the average span, making possible, of course, fewer points of anchorage along the right of way, fewer points of suspension and less steel in towers, etc.

2. It seemed logical to conclude that a line with

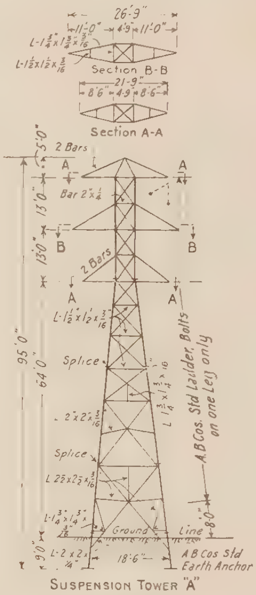

Fig. 2—Straight Suspension and Small Angle (Five Deg.) Tower

Philo-Canton
Philo-Crooksville
Fostoria-Lima
Twin Branch-Lima
} Lines (1923-1925)

fewer points of support, that is a line with fewer insulators in it, would be better electrically.

3. By lengthening the spans, it was possible to take full advantage of the additional mechanical strength obtainable in a steel-reinforced aluminum cable which, from a conductivity standpoint, it was possible to purchase on a cheaper basis at the time these lines were built than straight copper.

4. The experience that had been obtained both in the operation of the Windsor-Canton line and in the operation of a large number of 66,000-volt lines, some of which had been equipped with ground wires and others of which were not, as well as the correlation of similar operating experience of other engineers over that same section of the country, seemed definitely to indicate that the ground wire was doing more harm

than good on the lines about which anything was known, on operating voltages up to and including 132,000 volts. Definite examples extending over years were cited by the operating people to show that removal of the ground wire over sections of line where such ground wire had been giving trouble due to the ground conductor getting entangled in the main conductors under storm conditions or to breakage in other ways, had materially improved system operation and caused in no case any increased trouble. In fact, there did not seem to be any cases of trouble that could definitely be ascribed to the omission of such ground wires. In short, operating experience, although perhaps not properly evaluated, seemed to show that the ground wire was doing more harm than good and that an improvement in operation could be obtained by its omission. It was known, of course, that where the ground wire had given trouble it was brought about by mechanical weakness and that it was possible to install a ground wire free from such trouble, but when the expense of this was taken into consideration and balanced against the then existing experience, it did not seem worth while to make this additional expenditure.

The Philo-Canton and Philo-Crooksville lines were put into service in September, 1924, the Fostoria-Lima line was put into service August 1924, and the Twin Branch-Lima line was put into service September 1925, all of them being put into operation initially at the rated voltage, that is 132,000 volts, with the exception of the Fostoria-Lima line, which was operated at 66,000 volts until September 1925 when it was cut over to 132,000 volts. Very little trouble was experienced with the Philo-Canton line during 1924 although definite records are not available. It is believed, however, there were actually no flashovers. The history of this line during 1925 is shown in the tabulation under Table I which gives in as complete detail as was possible to obtain, 88 cases of trouble on the line. The experience falls naturally into four groups:

1. The group covered by cases 1 to 15 inclusive
2. The group covered by cases 16 to 35 inclusive
3. The group covered by cases 36 to 68 inclusive
4. The group covered by cases 69 to 88 inclusive

Analysis of the Four Groups

An examination of the first 15 cases of trouble shows that all but one case of trouble were exclusively in the top conductor. In 11 of the 15 cases one or more insulators were shattered and in 13 of the 15 cases considerable damage was done to the conductor. The question of the arcing and the points between which the arc took place has never been definitely cleared up although the table attempts to show how this actually happened. A check-up on this information, however, disclosed that the field inspectors in many cases were able to get no definite evidence and in a good many cases guessed as to what happened, very often not guessing correctly. However, the information was the best obtainable and has been allowed to stand for whatever light it may throw on the situation. It is perhaps pertinent to point out that the question of field information in all these cases is generally the most difficult question to take care of and is one of the reasons, perhaps, why so much loose thinking has been done on the subject.

The second group, covering cases 16 to 35, embodies experience on the same line with the so-called flux control units. The theory underlying it has been set forth by Mr. A. O. Austin in a group of papers which are given in the bibliography. The underlying idea is that an insulator placed at the end of the horn and mounted below the insulator string will give a screen effect and will prevent the formation of so-called streamers on the conductor and subsequent ionization and eventual breakdown of the air surrounding the insulator. Regardless of the apparent weakness of the theory, it was nevertheless decided to give this system a trial in view of the fact that information (and this information again had to be obtained in a hurry with no chance for proper investigation or check-up) given by other operating companies having systems of the same voltage was very emphatic in the statement that the application of this system had resulted in an almost complete elimination of the flashovers on their systems. It therefore seemed advisable, while the lightning season was on and in view of the fact that this equipment could be installed in very quick time, to give it a trial and find out exactly what it was worth. Consequently the two top conductors of the Philo-Canton line were equipped with these controls, one of the 10 units being removed to allow its installation without lessening the ground clearance. A typical view of such an installation is shown in Fig. 3. It shows,

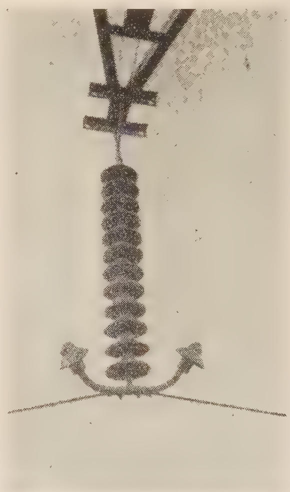

Fig. 3—Installation of "Flux-Control" on Philo-Canton Line

The change to 12 units was a later change, the original installation consisting of 9 units

TABLE I
REPORT ON INSULATOR FLASHOVERS, PHILO-CANTON LINE, 1925

Case No.	Pole or Tower No.	Type	Circuit No.	Angle & degree	Type insul. assem.	Units in string	Cross arm ext.	Ground wire	Top, middle or bottom conductors	Arcing protection	Damage to insulator
1	134	C	1	R-29	Strain	12	No.	No.	Top	2 horns	East string flashed —4 units shattered
2	133	A	1	0	Susp.	10	“	“	“	None	Three top units shattered
3	133	A	2	0	“	10	“	“	“	“	Entire string flashed
4	211	B	1	0	“	10	“	“	“	“	None
5	176	B	1	0	“	10	“	“	“	“	Entire string flashed top & bot. units shattered
6	130	B	2	0	“	10	“	“	“	“	Entire string flashed two top units shattered
7	230	B	1	0	“	10	“	“	“	“	Entire string flashed top unit shattered
8	230	B	2	0	“	10	“	“	Top & mid.	“	
9	227	A	1	0	“	10	“	“	Top	“	Entire string flashed top unit shattered
10	230	B	1	0	“	10	“	“	Mid.	“	Entire string flashed top unit shattered
11	202	A	1	0	“	10	“	“	Top	“	Entire string flashed two top units shattered
12	203	A	2	0	“	10	“	“	“	“	Entire string shattered
13	234	B	2	R-7	“	10	“	“	“	“	Entire string flashed none shattered
14	152	C	1	0	Strain	12	“	“	“	2 horns	None
15	152	C	2	0	“	12	“	“	“	“	
16	126	B	2	0	Susp.	9	“	“	“	Flux con.	Two insulators shattered
17	125	A	1	0	“	9	“	“	“	“	Top insulator flashed
18	125	A	2	0	“	9	“	“	“		Top insulator flashed
19	85	C	2	L-15	Strain	12	“	“	“	None	Two units shattered on Philo side
20	100	A	2	0	Susp.	9	“	“	“	Flux con.	Entire string flashed—two top units shattered
21	167	B	2	0.	“	9	“	“	“	“	Two top units shattered
22	167	B	1	0	“	9	“	“	“	“	None
23	176	B	2	0	“	9	“	“	“	“	Entire string flashed—two top units shattered
24	194	B	2	0	“	9	“	“	“	“	Top unit shattered
25	201	C	2	L-30	Strain	12	“	“	“	None	Two units shattered on Philo side
26	202	A	1	0	Susp.	9	“	“	“	Flux con.	Entire string flashed—2 top units shattered
27	203	A	1	0	“	9	“	“	“	“	Entire string flashed—1 top unit shattered
28	207	C	2	R-14	Strain	12	“	“	“	None	5 units shattered on inside string
29	209	B	2	0	Susp.	9	“	“	“	Flux con.	Entire string flashed—2 top units shattered
30	211	B	1	0	“	9	“		“	“	Two top units flashed
31	206	C	1	0	Strain	12	“		“	None	One string of insulators burned into
32	206	C	2	0	“	12	“		“	“	Several insulators flashed
33	50	A	2	0	Susp.	9	“		“	Flux con.	Entire string flashed—2 top units shattered
34	49	A	2	0	“	9	“		“	“	2 top & 2 bot. units shattered
35	66	A	2	0	“	9	“		“	None	Entire string flashed—3 units broken
36	249	B	2	0	“	9	“		“	Flux con.	Entire string flashed—top unit shattered
37	271	B	1	0	“	9	“		“	“	Entire string flashed—2 top units shattered
38	150	A	2	0	“	9	“		“	“	Top unit flashed
39	223	B	2	0	D-susp.	. .	“		“	“	Bot. unit broken—top unit flashed
40	271	B	1	0	Susp.	9	“		“	“	Entire string flashed—2 top units broken
41	249	B	1	0	“	9	“		“	“	Entire string flashed—2 top units broken
42	197	B	2	0	“	9	“		“	“	Top unit shattered
43	88	A	2	0	“	9	“		“	“	Top unit shattered
44	69	B	2	0	“	9	“		“	“	Top unit burned
45	40	A	2	0	“	9	“		“	“	Entire string flashed—3 top units broken
46	NSS	SS	1	. .	Switch	9	“		. .		. .
47	NSS	SS	1	. .	Bus		“		. .		. .
48	110	B	1	0	Susp.	9	“		Top	Flux con.	Entire string flashed—3 top units broken
49	237	C	2	0	Strain	12	“		Mid.	Arcing horns	1 string burned off—all but 3 units burned
50	272	B	2	L-1-38	Susp.		“		Top	Flux con.	2 top units broken—3 units flashed
51	167	B	2	0	“	9	“		“	“	Top unit broken
52	19	B	1	0	“	9	“		“	“	Entire string flashed—top unit broken
52	19	B	1	0	“	9	“		Mid.	None	Entire string flashed—top unit broken
52	19	B	1	0	“	9	“		Bot.	“	Entire string flashed—top unit broken
53	19	B	2	0	“	9	“		Top	Flux con.	Entire string flashed—2 top units broken
54	19	B	2	0	“	9	“		Mid.	None	Entire string flashed—top unit broken
55	153	A	1	0	“	9	“		Top	Flux con.	Entire string flashed—4 bot. units broken
56	210	B	2	0	“	9	“	No	“	“	2 top units flashed
57	166	C	1	0	D-susp.	9		“	“	“	2 top units broken
58	172	C	2	0	Strain	12	No	“	“	None	None
59	212	C	2	0	Strain	12	No	No	Top	None	2 units broken—1 flashed—both strings
60	NSS	Sub	1		Pillar	3		“	Top No. 1	“	
61	57	A	2	0	Susp.	9	No	“	Top	Flux con.	1 unit broken
62	270	C	1	0	Strain	12	“	“	“	None	None
63	200	C	1	0	“	12	“	“	“	“	1 unit broken
64	260	A	1	0	Susp.	10	“	“	Mid.	“	Top unit broken—3 units flashed
65	260	A	2	0	“	“	“	“	“	“	Top unit flashed
66	262	B	1	0	“	“	“	“	Bot.	“	2 units broken
67	262	B	1	0	“	“	“	“	Mid.	“	4 units broken
68	262	B	2	0	“	“	“	“	“	“	2 units broken
69	46	B	2	0	“	“	“	“	“	“	Entire string flashed—top & bot. units broken
70	132	A	2	0	“	“	“	“	“	“	Entire string flashed
71	132	A	2	0	“	“	“	“	Bot.	“	Entire string flashed top & bot. units broken
72	132	A	1	0	“	12	Yes	“	Top	Flux con.	Entire string flashed
73	132	A	1	0	“	10	No	“	Mid.	None	Entire string flashed—top unit broken
74	93	B	1	0	“	12	Yes	“	Top	Flux con.	4 top units broken
75	93	B	1	0	“	10	No	“	Mid.	None	Entire string flashed—top & bot. units broken
76	93	B	2	0	Susp.	10	No	No	Mid.	None	Entire string flashed—top unit broken
77	93	B	2	0	“	12	Yes	“	Top	Rings & horns	None
78	199	C	1	0	Strain	“	No	“	“	“	Entire string flashed—5 units broken
79	229	B	1	0	Susp.	“	Yes	“	“	Flux con.	6 units flashed
80	229	B	2	0	“	“	“	“	“	Rings & horns	Entire string flashed
81	230	B	2	0	“	“	“	“	“	Flux con.	Top unit broken
82	262	B	2	0	Susp.	12	Yes	No	Top	Flux con.	2 top units broken
83	276	A	2	0		12	Yes	No	Top	Flux con.	Entire string flashed—2 units broken
84	207	C	2	R-15	Strain	“	No	“	“	Ring & horn	1 unit broken—4 units flashed
85	151	C	2	0	“	“	“	“	“	“	None
86	232	B	2	0	Susp.	“	Yes	“	“	Flux con.	None
87	234	B	1	R-7	“	“	No	“	Bot.	None	Bot. unit broken
88	275	B	2	0	“	“	Yes	“	Top	Ring & horn	Entire string flashed—1 unit shattered

however, 12 units in the string, this being a change which will be discussed later. The original installation, however, went in with nine disk units.

An examination of cases 16 to 35 shows that the installation of these controls in no way minimized the trouble nor was there any change in shifting of the trouble from the top conductor to the other two conductors; in other words, all cases of trouble in this group were exclusively in the top conductor. The one marked change was that the shattering of the insulators seemed to be confined more closely to the two top units, the control assembly acting apparently as a not overwell designed horn and as such being subject to considerable burning of its own. This is shown in

TABLE I Continued

REPORT ON INSULATOR FLASHOVERS, PHILO-CANTON LINE, 1925

Case No.	Damage to arcing protection	Damage to conductor	Power arcover string	Arc			
				From	To	From	To
	¾″ burned off ends both arcing horns	None	Yes	Horn	Horn	. .	
1	. . . .	Pitted aluminum over wide stretch	"	Cond.	Brace	. .	Cage
2	. . . .	Cond. badly burned—4 str. steel holding	"	"	"	. .	"
3	. . . .	Badly burned 25′ north of clamp 3 str. stl. Holding	No	"	"	. .	"
4	. . . .	None	Yes	Clamp	Top cap	. .	
5	. . . .	Badly pitted 45′ toward Canton	"	Cond.	"	. .	
6	. . . .	Outer layer A1 burned toward Philo 12′	"	"	Cage	. .	Top cap
7	. . . .	Outer layer A1 burned toward Philo 12′	No	"	"	. .	Brace
8	. . . .	3 strands A1 burned 3″ from clamp	Yes	"	Top cap	. .	
9	. . . .	Outer layer A1 burned 12′ toward Philo	"	Cond.	"	. .	
10	. . . .	Alum. burned thru stl. core not dam.	"	"	"	. .	
11	. . . .	Top layer alum. burned 5′ toward Philo	"	"	Cage	. .	Top arm
12	. . . .	Top layer alum. burned 5′ toward Philo	"	"	Top arm	. .	
13	None	Cond. badly burned in loop	No	Loop	Cage	. .	Top arm
14		Cond. badly burned in loop	"	"	"	. .	"
15	Flux control insul. broken—arm burned	Aluminum burned thru	Yes	Fluxcont.horn	Top	. .	
16	. . . .	Conductor pitted	"	Cond.	Cage	. .	
17	. . . .	Conductor pitted	"	"	"	. .	
18	. . . .	None	"	"	Top arm	. .	
19	1 flux control unit shattered hole burned in arm	Cond. damaged 25′ toward Philo	"	"	Cage	. .	Top arm
20	1 flux control unit shattered	None	"	F C A	Top cap	. .	
21	. . . .	Cond. damaged 7′ toward Philo	No	Cond.	Cage	. .	
22	. . . .	Cond. damaged 6′ toward Canton	Yes	"	Top	. .	
23	1 flux control unit burned	Cond. damaged 30′ toward Canton	"	Flux cont. arc	Top cap	. .	
24	. . . .	Cond. badly burned in loop	"	Loop	"	. .	
25	Flux control arm pitted	Cond. badly burned 15′ toward Canton	"	Cond.	Cage	. .	Top arm
26	1 flux control unit damaged	None	"	flux cont. arm	"	. .	
27		Cond. badly burned in loop	"	Cond.	Top arm	. .	
28	1 flux control unit & arm burned	Cond. burned both sides of clamp	"	F C A	Cage	. .	Top arm
29	1 flux control unit broken	Cond. damaged 25′ toward Canton	"	"	Top	. .	
30	. . . .	Cond. badly burned in loop	"	Loop	Top cap	. .	Top arm
31	. . . .	Cond. badly burned in loop	"	"	Top arm	. .	
32	1 flux control unit shattered	Cond. damaged 20′ toward Philo	"	Cond.	"	. .	
33	1 flux control unit shattered arm burned	Cond. damaged 10′ on Canton & 4′ on Philo side	"	F C A	Cage	. .	Top arm
34	. . . .	Cond. pitted 10′ toward Canton	"	Cond.	Top arm	. .	
35	1 flux control unit shattered—arm burned	Cond. burned 2′ from clamp	"	F C A	Cage	Cond.	Top cap
36	1 flux control unit shattered	Cond. burned 10′ toward Philo	"	Clamp		. .	"
37	1 flux control unit shattered—arm burned	None	"	C C A	Cage	Cond.	"
38	1 flux control unit shattered end of arm	None	"	"	"	. .	"
39	1 flux control unit shattered hole burned in arm	Cond. damaged both sides	"	"	"	Cond.	"
40	1 flux control unit shattered	Cond. damaged 2′ toward Philo	"	"	"	"	"
41	1 flux control unit shattered	None	"	"	. .	. .	"
42	1 flux control unit shattered hole burned in arm	None	"	"	. .	. .	"
43	1 flux control unit flashed	None	"	"	Cage	. .	"
44	1 flux control unit shattered arm burned off	Cond. damaged 10′ toward Philo	"			. .	"
45	. . . .	. . . .		?	?	?	?
46	. . . .	. . . .					
47	1 flux control unit shattered arm burned	Cond. burned 15′ toward Canton	Yes	F C A	brace & cage	Cond.	Top & cap
48	Arcing horn tower end 1″ burned off	Cond. slightly pitted in loop	Yes	Horn	Horn	. .	Tower cap
49	None	Cond. slightly pitted	"	Clamp		Cond.	Top cap
50		Cond. badly burned on Philo side	"	Cond.	Cage	. .	"
51	Flux control unit flashed—arm burned	Cond. pitted 328′ toward Philo	"	"	. .	. .	"
52	. . . .	Cond. pitted 320′ toward Philo	"	"	. .	. .	"
52	. . . .	Cond. pitted 175′ toward Philo	"	"	. .	. .	"
52	None	Cond. burned 2′ toward Philo	"	"	. .	. .	"
53	. . . .	Cond. burned 2′ toward Philo	"	"	. .	. .	"
54	Flux control arm burned off	Cond. damaged 10′ toward Canton	"	F C A	Cage	Cond.	"
55	Flux control unit burned	Cond. damaged 5′ toward Philo	"	Cond.	Top cap		Hanger
56	Flux control unit shattered	None	"	F C A	Top arm		Top cap
57	. . . .	Loop badly burned	No	Loop	Cage		Top arm
58	. . . .	Loop burned	Yes	Clamp	Tower yoke		Tower cap
59			Yes	Blade contact	Ground Steel		
60	None	Cond. burned toward Canton	No				
61	. . . .	Loop and 10′ of cond. toward Philo dam	Yes	Cond.	Midarm Brace		
62	. . . .	None	"				
63	. . . .	Cond. burned both sides of clamp	Yes	Cond.	Top cap		
64	. . . .	None		Not determined			
65	. . . .	Cond. burned 20′ toward Canton	"	Cond.	Top cap		
66	. . . .	Cond. burned 20′ toward Canton	"	"	"		
67	. . . .	Cond. burned 20′ toward Canton	Yes	"	"		
68	. . . .	None	"				
69	. . . .	Cond. burned 15′ toward Philo	"	Cond.	Top cap		Bot. top Phase
70	. . . .	Cond. burned 15′ toward Philo	"	"	"		Mid phase
71	None	None	"	"	"		
72	. . . .	None	"	"	"		
73	None	None	"				
74	. . . .	None	"	Clamp	Top cap		
75							
76	. . . .	Cond. damaged 15′ toward Philo	"	Cond.	Top cap		
77	. . . .	Cond. damaged 15′ toward Philo	"	Mid. cond.	Top cond.		
78	Ring marked—3″	None	"	Ring	Top caps		
79	None	Cond. damaged 40′ toward Philo	"	Cond.	Top arm		
80	None	Cond. damaged 15′ toward Philo	"	Ring	Horn		
81	None	Cond. damaged 30′ toward Philo	"	Cond.	Top cap		
82	. . . .	Cond. damaged 3′ toward Canton—6′ toward Philo	Yes	Cond.	Top cap		
83	2 flux control units broken	Cond. dam 2′ toward Philo	Yes	F C arm	Top arm		
84	None	Loop & cond. toward Canton pitted	No	Loop	Top cap		
85	None	Cond. pitted in loop	"	"	Top arm		
86	1 flux control unit broken	None	"				
87	. . . .	Cond. slightly damaged	Yes				
88	None	Cond. burned 5′ toward Philo	"	Ring	Horn		

Figs. 4 and 5, which are quite typical as to what happened to some of the horns after flashover.

The next group, which covers cases 36 to 68, covers a period during which a new series of changes was made on the line in an attempt to see whether, without resorting to a ground wire, flashover could not be prevented or reduced to a point where its effect would be harmless or practically so. In view of the fact that the

TABLE I Continued

REPORT ON INSULATOR FLASHOVERS, PHILO-CANTON LINE, 1925

Case No.	Date of failure	How trouble was located	Line opened automatic or manuel	No. times line opened	Line out at (time)	Line in at (time)	Did line open at both ends	Means taken to correct	Weather Conditions
1	3–26	Call by employee	Auto.	1	5:48 P M	5:51 P M	Yes	Remove arc horns	Rain & Lightning
2	3–26	Call by employee	"	1	5:52 P M	5:53 P M	"	Flux control	" "
3	3–26	Call by employee	"	1	"	"	"	Flux control	" "
4	4–2	Call by farmer	"	1	6:00 P M	6:33 P M	"	Flux control	" "
5	4–16	Normal patrol	. .	0	. .	. .	. .	Flux control	" "
6	4–19	Normal patrol	Auto.	1	11:28 A M	11:29 A M	Yes	Flux control	Rain, Light, Wind
7	4–25	Normal patrol	"	1	8-22 P M	8:31 P M	Canton	Flux control	Rain & Lightning
8	4–25	Normal patrol	"	1	"	8:30 P M	"	Flux control	"
9	4–25	Normal patrol	"					Flux control	"
10	4–25	Normal patrol	"					Flux control	"
11	4–25	Special patrol	"					Flux control	"
12	4–25	Normal patrol	"	1	8:24 P M	8:30 P M	Philo	Flux control	"
13	?	Normal patrol	"					Flux control	"
14	5–16	Call by employee	"	1	9:28 P M	9:23 P M	Canton	Remove arc horns	"
15	5–16	Call by employee	"	1	"	"	Yes	Remove arc horns	"
16	5–16	Normal patrol	"	1	7:45 P M	7:47 P M	"	Flux control	"
17	?	Call by employee	"	1	9:26 P M	9:28 P M	"	Flux control	"
18	?	Call by employee	"					Flux control	"
19	5–21	Special patrol	"	2	3:52 P M	3:55 P M	Yes	Remove arc horns	"
20	5–23	Call by employee	"	1	9:26 P M	9:27 P M	"	Flux control	"
21	5–21	Normal patrol	"	1	3:52 P M	3:53 P M	"	Flux control	"
22	5–21	Normal patrol	"					Flux control	"
23	5–21	Normal patrol	"	1	3:54 P M	3:55 P M	Yes	Flux control	"
24	5–23	Normal patrol	"	1	9:26 P M	9:27 P M	"	Flux control	"
25	5–23	Normal patrol	"	1	10:25 P M	10:26 P M	"	Remove arc horns	"
26	5–21	Normal patrol	"	1	10:43 P M	10:44 P M	"	Flux control	"
27	5–21	Call by employee	Auto.(#2)	1	10:51 P M	10:52 P M	"	Flux control	"
28	6–6	Normal patrol	Auto.(#2)	1	12:02 P	12:04 P	"	Remove arc horns	"
29	6–6	Normal patrol	Auto.(#1)	1	12:04 P	12:05 P	"	Flux control	"
30	?	Normal patrol	Auto.(#1)	1	12:04 P	12.06 P	"	Flux control	"
31	6–6	Normal patrol	Auto(#1,2)	1	12:06 P	12:08 P#2	"	Remove arc horns	"
32	?	Normal patrol	Auto.(#2)	1	132 P	1:33 P	"	Remove arc horns	"
33	6–6	Normal patrol	Auto.(#2)	1	158 P	1:59 P	"	Flux control	"
34	?	Normal patrol	Auto.(#2)	1	2:04 P	2:05 P	"	Flux control	"
35	3–26	Normal patrol	Auto(#1,2)	4			"	Flux control	"
36	6–24	Normal patrol	Auto.	1	11:30 P M	11:32 P M	"	Add units X-arm ext. R.& H.	"
37	7–2	Normal patrol	"	2	10:29 A M	10:31 A M	"	Add units X-arm ext. R.& H.	"
38	6–27	Call by employee	"	1	3:12 P M	3:13 P M	"	Add units X-arm ext. R.& H.	"
39	"	Normal patrol	"	1	"	"	"	Add units X-arm ext. R.& H.	"
40	7–2	Normal patrol	"	2	10:29 A M	10:31 A M	"	Add units X-arm ext. R.& H.	"
41	"	Normal patrol	"	2	"	"	"	Add units X-arm Flux control	"
42	7–7	Normal patrol	"	1	2:47 P M	2:48 P M	"	Add units X-arm R. & H.	"
43	"	Normal patrol	"	1	2:52 P M	2:53 P M	"	Add units X-arm flux control	"
44	"	Normal patrol	"	1	2:54 P M	2:55 P M	"	Add units X-arm R. & H.	"
45	7–4	Normal patrol	"	4	4:10 P M	4:12 P M	"	Add units X-arm flux control	"
46	7-6 to 11	Redman	. .	. .	. .	. .	. .	. .	"
47	7-6 to 11		. .	. .	. .	. .	. .	. .	"
48	7–2	Normal patrol	Auto.	2	10:29 A M	10:31 A M	Yes	Add units X-arm ext. R.&H.	"
49	7–10	Report by Hare	"	1	3:36 A M	3:37 A M	"	None	"
50	7–10	Report by Hare	"	1	3:52 A M	3:53 A M	"	Add units X-arm ext. R.& H.	"
51	7–10	Normal patrol	"	2	4:02 A M	4:03 A M	"	Add units X-arm flux control	"
52	7–10	Normal patrol	Manuel	1	8:00 A M	8:04 A M	Philo	Add units X-arm flux control	"
52	7–10	Normal patrol	"	1			"	None	"
52	7–10	Normal patrol	"	1			"		"
53	7–10	Normal patrol	Auto.	1	8:00 A M	8:03 A M	Yes	Add units X-arm ext. R.& H.	"
54	7–10	Normal patrol	"	1	"	"	"	None	"
55	7–25	Call employee	"	1	9:19 P M	7:20 P M	Philo	Add units X-arm ext. R.& H.	"
56	7–16	Normal patrol	"	1	1:04 P M	1:05 P M	Yes	Add units extend arm	"
57	7–25	Call E*	"	1	7:19 P M	7:20 P M	Philo	Add units extend arm	"
58	7–7	Normal patrol	"	1	2:54 P M	2:55 P M	Yes	Extend arm	"
59	7-16-25	Normal patrol	Auto	1	12:34 P M	12:35 P M	Yes		"
60	7–25	Call E*	"	1	7:10 P M	7:20 P M	Philo		"
61	7-16-25	Call E*	"	1	1:04 P M	1:05 P M	Yes	R.& H.* Add units extend arm	"
62	7-25-25	Call E* Hare	"	1	7:19 P M	7:20 P M	Philo	R.& H*	"
63	8–5	Call E* Hare	"	1	10:53 P M	10:55 P M	Yes	R.& H.*	"
64	"	Call E*	"	1	"	"	"	None to date	"
65	"	Call E*	"	1	"	11:01 P M	"	None to date	"
66	?	Call E*	Probably ca	used from				None to date	"
67	?	Call E*	Trouble of	8-5-25				None to date	"
68	8–10	Call E*	Auto.	2	3:31 P M	7:43 P M	Canton	None to date	"
69	8–18	Special patrol	"	1	10:10 P M	10:11 P M	"	9-1-25 add 2-units	"
70	"	Special patrol	"	1	"	"	"	9-1-25 add 2-units	"
71	"	Special patrol	"	1	"	"	"	None to date	"
72	8–12	Special patrol	"	1	11:05 P M	11:06 P M	Yes	9-1-25 add 2 units to mid. cond.	"
73	"	Special patrol	"	1	"	"	"	9-1-25 add 2 units to mid. cond.	"
74	9–3	Call E* Sowell	"	1	4:03 A M	4:05 A M	Canton only	9-1-25 add 2 units to mid. cond.	"
75	"	Call E* Sowell	"	2	4:07 A M	4:46 A M	Yes	9-1-25 add 2 units to mid. cond.	"
76	9–3	Special patrol	Auto.	7	4:03 A M		Yes	9-1-25 add 2 units to mid. cond.	"
77	"	Special patrol	"	7		5:11 A M	"		"
78	"	Special patrol	"						"
79	"	Special patrol	"	Caused by	trouble				"
80	"	Special patrol	"	of	9–3				"
81	"	Special patrol	"						"
82	9–3	Special patrol	Auto.						"
83		Normal patrol							Unknown
84		Call E*							"
85		Normal patrol							"
86		Normal patrol							"
87		Normal patrol							"
88		Normal patrol							"

so-called flux control unit very definitely did not seem to do what the sponsors claimed it would do, it was decided to test out three other changes and these consisted of the following:

1. The top-arm was extended two and one-half feet in each direction, making it the same length as the middle arm and the hanger of the middle arm was lowered approximately 2 ft., 10 in. on the cage. This is shown in Fig. 6. This made it possible to increase the insulation on the top arm, where the trouble again seemed to be centered, from the original 10 units to 12 units, and this change was made on the entire line. This, of course, was based on the theory that the lightning voltages were not very much in excess of the flash-

over voltage of the top string and it was thought possible that the installation of two additional units would raise the flashover of the string to such a point that the

FIG. 4—TYPICAL BURNING OF "FLUX-CONTROL" HORNS AND INSULATORS PHILO-CANTON LINE (1925)

induced voltage would not exceed the flashover voltage of the string in at least, say, 90 per cent of the cases.

2. The moving out of the point of attachment of the top string of insulators resulted in a greater clearance between it and the second arm hanger. The object of this, of course, was to increase the flashover distance to the surrounding structure.

3. In addition to these changes which were carried through not only on the Philo-Canton line, but also on the Philo-Crooksville, Fostoria-Lima, and Lima-Twin Branch lines, there was installed on the Philo-Canton line the following equipment:

An 18 in. times 22 in. cast-iron arcing ring was em-

FIG. 5—TYPICAL BURNING OF "FLUX-CONTROL" HORNS AND INSULATORS PHILO-CANTON LINE (1925)

ployed on the lower end of the upper string and a 24-in. arcing horn mounted parallel to the conductor. This assembly was used on only one side of each tower and the flux control assembly was maintained on the opposite side, alternating the position of the two on successive towers so that for each circuit there were installed an equal number of arcing rings and "flux controls." There was no change made in the flux control assembly from what was originally employed with the exception of the fact that three-insulator units were added (making 12 in all); also where any damage had been done to the assembly the damage was repaired.

Fig. 7 shows a straight-arcing ring and horn-suspension assembly, and Fig. 8 is a drawing of this same assembly.

In the case of dead-end assembly a 33-in. diameter-pipe ring with a double horn was employed; Fig. 9 is a photographic view of such an assembly after the flashover described under case No. 78.

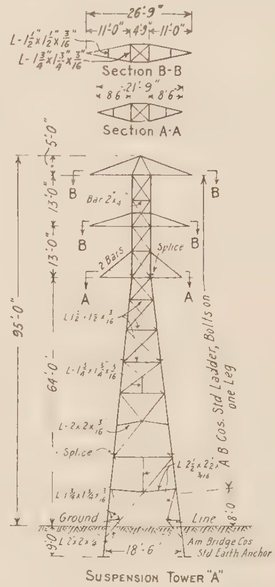

FIG. 6—CHANGES MADE IN UPPER AND MIDDLE ARMS PHILO-CANTON LINE (1925) TO OBTAIN LARGER CLEARANCE

While the troubles listed under cases 36 to 68 were taking place, the changes enumerated above were being made all at the same time, the changes being made on only one circuit at a time during the daytime and the circuit being put back into service at night. It will

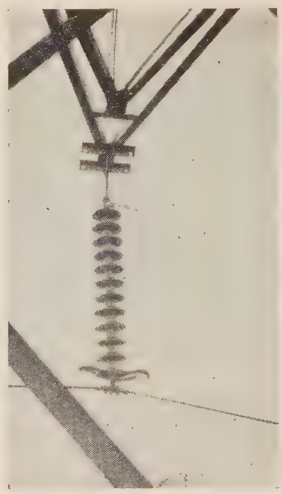

FIG. 7—ARCING RING AND HORN ASSEMBLY, PHILO-CANTON LINE (1925)

be noticed that in 24 of the 33 cases, the trouble was again on the top conductor and that in all but five of the cases the flux control was employed. In general the type of damage was the same as that in group two, consisting of considerable damage to the string, to the conductor, and to the flux control unit. Where no

arcing protection of any kind was employed, that is on the middle and bottom conductors, the damage in some cases was more severe and in other cases less than in the two upper conductors. It is to be noted that among this group, while there were some units in service with the arcing ring protection, there were no cases where any damage was sustained to units with such protection.

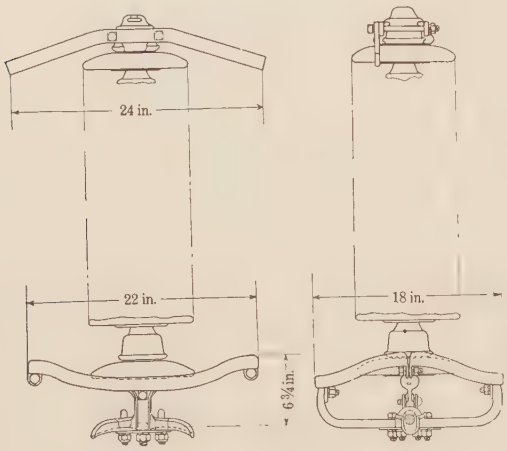

FIG. 8—ARCING RING AND HORN ASSEMBLY FOR SUSPENSION TOWER PHILO-CANTON LINE (1925)

The last group, namely cases 69 to 88 inclusive, extended over a period of time of well over two months and during the course of this period no changes of any kind except those described previously, were made. It will be seen that of the 20 cases, 13 occurred on the top conductor, five on the middle conductor, and two on the bottom conductor. Of the 13 top-conductor failures, seven were cases in which flux control had been employed and six in which rings and horns had been employed, but with this difference: in five of the seven cases employing flux control one or more insulator units were shattered, but only in three of the six cases employing rings and horns were any insulators damaged. Again, while in four of the seven flux-control cases there was damage done to the conductor, and in the case of the rings and horn combination three of the six cases resulted in damage of conductor, the extent of the damage in the case of the horn combination seems to have been less than in the case where the flux control has been employed.

FIG. 9—DEAD END ARCING RING AND HORN ASSEMBLY PHILO-CANTON LINE (1925) AFTER FLASHOVER CASE NO. 78

(See Table I.)

The troubles encountered on the Twin Branch-Lima and the Fostoria-Lima lines were almost negligible in comparison with the trouble that was encountered on the Philo-Canton line. In the case of the Fostoria-Lima line only one flashover was experienced and that was on a top conductor during a period when the line was operated at 66,000 volts. The conductor was slightly damaged but no damage was sustained to the insulators. In the case of the Twin Branch-Lima line only three cases of flashovers due to lightning were experienced in 1925, two being on the top conductor and one on the middle conductor. In each of these cases at least two insulators were shattered but no damage was done to the conductor. On the Philo-Crooksville line in a period of considerably over a year, there were two cases of flashover but neither case caused trouble of serious consequence.

RELAY PROTECTION

At the beginning of 1925 the following scheme of protection was employed on the Philo-Canton line. At the Philo end current-balance relays were employed, operating only in case both lines were in circuit, and separate overload relays were employed on each of the two lines. The balance relays were operating on a so-called cross-connection and the lines were interlocked with a locking-out relay to render the second line non-automatic for a period of five sec. in case of the functioning of the switch on the first line. At the Canton end, cross-connection with a duo-directional reverse power relay was employed with fast and slow overload relays, the fast relays operating only with both lines in. The two feeders here were also interlocked with a five sec. locking-out relay. As the lines continued to be damaged some changes were made in the direction of speeding up the interlocking time and also in the direction of speeding up the relays at the Canton end. In October, there were installed at the Canton end of the line a set of current-balance relays similar to those at the Philo end but the duo-directional reverse power relay was maintained to select between the Windsor-Canton and Philo-Canton lines in case of one-line operation throughout. In general, the relays functioned entirely satisfactorily and it is not believed that the severe burning which took place was caused in any way by the failure of the relays to clear the circuits quickly enough, the relay settings being as fast as could possibly be obtained without endangering normal operation.

A MORE DETAILED ANALYSIS OF TROUBLES

While these troubles were occurring it was impossible to get any accurate data as to what was happening. Lines were flashing-over; insulators were being shattered; the conductor was being burned; and the field

forces were too busy trying to place the line in an operating condition with a minimum delay to be able to give very much attention to the details of what was happening. Things were happening so thick and fast that there was no opportunity to stop and consider the matter calmly. With the approach of the end of the lightning season a little more time could be taken to determine what had actually happened and to make an intelligent analysis.

First, toward that end, was the gathering together of data with regard to the trouble shown in the tabulation under Table I. This tabulation was very carefully gone over and a survey was made in the field to supplement, if possible ,the information given therein. In the course of this investigation it was found how very little knowledge as to what actually happened was obtainable and the smallness of the amount was really surprising. It was found, as a careful review of the troubles tabulated in Table I will show, that there existed a good deal of conflicting data and that a good many of the reports which were supposed to have been based on observation at the time the repairs were made, were entirely unreliable. However, this much stood out with bold clearness. The Philo-Canton line had been subjected to an unusual amount of punishment from lightning. That it was due to the fact that the area which it traversed was a particularly stormy area there was very little doubt. There also did not seem to be any doubt that the measures that had been taken up till then were none of them completely effective and some of them were almost negligibly so. Further, a calm review of what had been done and the lines that had been followed brought home clearly the fact that designing a line merely to withstand lightning voltages was certainly not a proper procedure since it resulted in placing insulation on the lines of such a value that it could not possibly be matched economically by that of the transformers, oil switches, and other apparatus connected to the system.

Simultaneous with the gathering of the field data a very thorough review was made of the work in connection with this subject done by Steinmetz, Creighton, Austin, Peek and others, and particularly their work in connection with the ground wire.

Viewing the troubles encountered on the Philo-Canton line, after an analysis had been made of all the available field data, and in the light of the work of the other investigators mentioned, the explanation that seemed to stand up best came down to the following:

1. The Philo-Canton line traverses an unusually stormy country and the year 1925 seems to have been an unusually severe year from the standpoint of lightning.

2. The height of the particular tower was considerably higher than any that had been previously constructed on the system and this resulted in potentials being induced in the upper two conductors during lightning higher than those that were encountered on the Windsor-Canton line by at least 300,000 to 400,000 volts.

3. The omission of the ground wire subjected the insulator strings to this full voltage and this value was sufficient often enough during 1925 to give the large number of cases of trouble that are tabulated.

4. The fact that the Twin Branch-Lima and the Fostoria-Lima lines were not subject to these flashovers can be explained by the following:

a. The first of these two lines did not operate for a sufficiently long period during the lightning season.

b. The Fostoria-Lima line was in for a whole year but most of the time it was operating at 66,000 volts and its performance when insulated for 132,000 volts with a follow-up voltage of 66,000 volts would, of course, be expected to be considerably different from what it would be with a follow-up voltage of 132,000 volts.

c. From general observations taken, it appeared indisputable that the lightning in the territory traversed by these two lines was not anywhere near the same severity as that encountered along the Philo-Canton line.

Viewed thus a satisfactory solution seemed attainable by adopting the following methods:

1. Preventive. Installation of ground wire to reduce the lightning voltages.

2. Remedial. Where, either because of the severity of the lightning or because of the great importance of the load, no *chances* could be taken, the installation of arcing rings and horn devices to clear the insulator string and the conductor in case of spill-over.

Before definitely embarking on this course, it seemed advisable to check this proposed solution and consequently a series of tests was carried out with the lightning generator of Peek to determine the effectiveness of the ground wire on the tower shown in Fig. 2. These tests showed definitely that a reduction amounting on the average to about 50 per cent in the value of the induced voltage could be obtained by the instal-

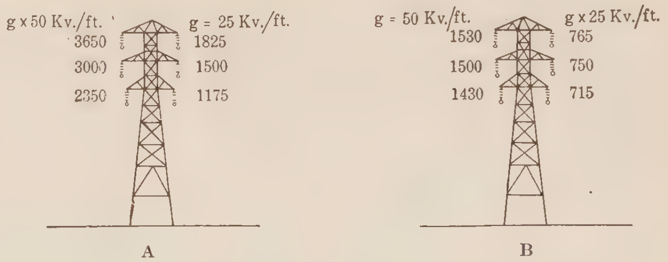

FIG. 10—GROUND WIRE TESTS ON PHILO-CANTON 132 K. W. TOWER

A. No ground wire B. With ground wire

lation of one ground wire at the peak of the towers. This is shown in Fig. 10, which shows the induced potential in A, suspension, B, moderate angle, and C, dead-end towers—the height of the crossarms is the

same in each case and is shown in Fig. 2—with and without ground wires, under conditions of a potential gradient of 50-kv. per foot of height, and of 25-kv. per foot of height.

Another phase of the investigation was a series of tests in connection with the arcing rings and horns which it was thought advisable to employ on the towers traversing territory particularly susceptible to lightning. Before working out the designs, a series of tests was

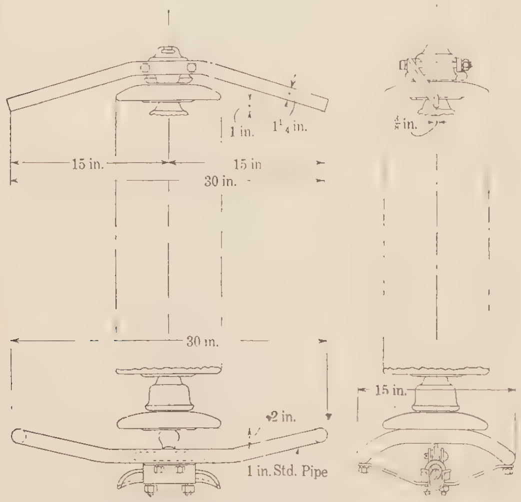

FIG. 11—ARCING RING AND HORN ASSEMBLY (1926 INSTALLATION) FOR SINGLE SUSPENSION STRING—PHILO-CANTON LINE

carried out in the high-voltage engineering laboratory at Pittsfield, to determine the specific shapes and sizes of horns and rings and their placement on the string to clear a power arc from the insulator string and from the

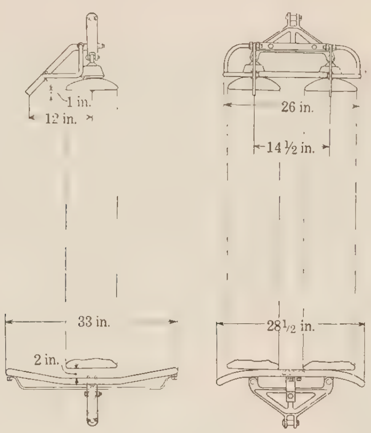

FIG. 12—ARCING RING AND HORN ASSEMBLY (1926 INSTALLATION) FOR DEAD END STRING PHILO-CANTON LINE

conductor if flashover should take place and should be followed by a power arc. The rings and horns that were worked out as well as their relations to the string and to the conductors are shown in Figs. 11 and 12 which show the designs for a straight suspension string and for a straight dead-end string. A similar design was worked out for the double suspension string.

As a result of all these studies and investigations, ground-wire installation was decided upon on all 132-kv. steel tower lines that had been erected since the beginning of the Philo-Canton line, or that were in process of erection by the end of 1925, all of which were erected without ground wire. In addition, arcing rings and horns were laid out for the Philo-Canton line and for a number of other lines where either, as in the case of Philo-Canton, it was known that lightning conditions were very bad, or where, because of the existence of but a single circuit between stations, it was imperative to keep the outage time in that circuit as near zero as possible.

DESIGN OF GROUND WIRE AND CONNECTIONS

It is conceded among engineers that the disrepute into which the ground wire had fallen was due primarily to the fact that it had been put up more or less on the basis that it was merely an appendix to the line, and since it was not carrying any energy, and therefore not earning its way, that it ought therefore to be put in with as little expense as possible; this resulted in almost every case in the installation being as poor a one as possible. The conductors employed were very seldom anything but galvanized steel wire, and that was generally of a very much smaller diameter than the main conductor and of a lesser number of strands. The attachment was generally of some clamp type; the sagging of the ground wire was given very little consideration; and all in all the thing was put in in a most non-engineering manner. As a consequence troubles of all sorts were encountered with the ground wire. Three or four years after the installation the wire as a rule would begin to rust and a short time after that breakages would crop out in various sections of the line, resulting in grounds and short circuits being placed on the system. In many cases, too, the main line would swing into the ground wire or the ground wire into the line due to their unequal sags or due to their unequal swings.

It has always been known that if a ground wire similar to the main conductor were employed and the same attention given to its installation as given to the main conductor, these troubles could be avoided, but with the exception of a very few cases the authors do not know of any installations that were put in on that basis. In view of the fact that the decision to install the ground wire was reached after considerable trouble without it, and after a conviction that the ground wire would remedy a considerable portion of this trouble, it was deemed advisable not to repeat the mistakes of handicapping the ground wire through poor installation. On the other hand, it was felt that if there were any ways that the installation could be made cheaper than that which would obtain by the use of a straight line conductor, advantage should be taken of these means. Accordingly, there was worked out in conjunction with the conductor manufacturer, a special 159,000 cir. mil. A. C. S. R. conductor con-

sisting of twelve 0.1151 in. diameter aluminum strands and seven 0.1151 in. steel strands, and this conductor was found to have mechanical characteristics so closely similar to that of either 336,400 or 397,500-cir. mil that under most conditions it could be used interchangeably with them.

More attention than is usual was given to the hardware and to the method of attachment of the ground wire.

Application of Experience to Tower Line Design

The authors believe that theoretical analysis and their experience in operation applied to tower-line design with a view particularly of designing the lines for continuous service can be summed up as follows:

1. It is essential that a balance be maintained between the height of tower, the length of span, and the lightning voltage that may be expected in the conductor span. As a general rule the cost of the line can be decreased by increasing the length of span, but carried beyond a certain point the continuity of service to be expected from the line is bound to be decreased materially in the raising of the height of the conductors. The standard suspension insulator has been developed to such a point at the present time that the increased number of points of attachment on the line will have materially less effect on lowering the continuity of service than will the raising of the height of the conductor.

2. A proper balance should be maintained between the number of insulators employed per string, the insulating values employed on other apparatus on the system, and the clearance to ground. Insulating a line sufficiently high to prevent flashover in a great majority of cases, will result as a general rule (except perhaps in certain types of lines operating at 220 kv. or higher voltages) in overinsulating the lines at the expense of the rest of the equipment and will result in failures at station and substation points.

3. Unless the line is very low, it is believed that steel-tower structures carrying power conductors of 44,000 volts and over should in general be designed and installed with a ground wire. It is fully realized that there may be locations and conditions under which this is not practicable, for example, in territory where the soil conditions are such that the ground resistance is very high, and where consequently the effectiveness of the ground conductor is minimized to an almost negligible value; but these are special cases. There may also be cases in territory that is particularly lightning-free where no ground wire would be justified. In no case, the authors believe, should the use of a ground wire be dismissed without giving full consideration to the known lightning conditions of the territory over which the line has to traverse, to the height of the tower, to the insulation proposed for the tower, and to their relations to the lightning voltages that might be expected on the power conductors.

4. If a ground wire is installed it should be accepted as an essential part of the line and its installation treated the same as that of the main conductors, full attention being given to the material of the conductor itself and to its method of attachment and stringing. There is no reason why the main power conductor should be designed for a possible 50 years of life and the ground conductor designed for a life equal to 10 per cent of that.

5. It is possible that a line will have to be built of so great a height, because of the contour of the country or for some other reason, that even with the use of a ground wire, sufficient protection will not be obtained to keep the number of flashovers down to a low enough point. In these cases, the authors believe it would be well to install remedial devices in the form of arcing rings and horns or their equivalents to prevent conductor burning and insulator shattering in case of a flashover.

6. The line must be designed so that its switching arrangement is correct; that is, the line must be so designed that it can be relayed properly and disconnected from the rest of the system quickly in case of trouble.

Acknowledgment is hereby made to Mr. F. W. Peek, Jr., and Mr. W. L. Lloyd, Jr., of the General Electric Company, and to Mr. A. O. Austin of the Ohio Brass Company for their assistance in carrying out some of the investigations, and to Mr. Frank Howard, of the Ohio Power Company, for his assistance in carrying through some of the developments and in obtaining the field data.

The complete paper gave a complete record of the relay settings on the Philo-Canton line during 1925, a discussion of the action in regard to the design of new towers taken during the period of trouble, a discussion of the research work on the subject of the ground wire done by various investigators, the results of an investigation of the relationship between the length of the insulator string and clearance of the string to ground to obtain a balance between the two, and an outline of plans for obtaining complete information on the future behavior of these lines.

NEW ELECTRIC CODE FOR MEXICO

Demand for electrical supplies in Mexico have been stimulated by the issuance of a new electric code, which raises the standard of permitted equipment. Existing installations shall be made to conform to the new code by July 11, 1926, but the Department of Industry, Commerce, and Labor is authorized to extend the period if necessary.

The code is an adaptation to Mexican conditions of codes of the United States. The National Electrical Code and the National Safety Code are drawn on extensively. A number of changes from American practises are introduced, such as longer spans between poles and more lenient wiring regulations, as there is considerable use of stone and concrete in the construction of Mexican homes.

Zero Method of Measuring Power with the Quadrant Electrometer

BY W. B. KOUWENHOVEN* and PAUL L. BETZ†

Member, A. I. E. E. — Student Member, A. I. E. E.

Synopsis.—*This paper describes a zero method of measuring power by means of the quadrant electrometer developed by the authors, and which we believe to be new. Zero deflection of the electrometer is obtained by opposing the torque produced by the a-c. load by means of a counter torque set up by continuous potentials introduced into the electrometer circuit. The continuous potentials required are small in value and easily handled.*

We have derived the equations that apply to the method and checked their correctness by experimental observations on resistance, capacity, and inductive circuits.

THE importance of the quadrant electrometer as an instrument for measuring the power factor and loss in dielectrics and cables is well recognized. The quadrant electrometer wattmeter has also prove valuable in measuring iron losses in small specimens.

The usual connections for using the quadrant electrometer as a wattmeter are shown in Fig. 1. In Fig. 1, N is the needle; Nos. 1 and 2 are the respective quadrant pairs which are enclosed in the case of the electrometer. The deflection of the electrometer is proportional to the vector product of the load voltage V and the voltage drop across the quadrants, 1 and 2, caused by the load current I flowing through the non-inductive resistance R_1. If it is impossible to apply full voltage to the needle of the electrometer, a fractional part of the supply voltage may be applied to the needle as indicated by the dotted line in Fig. 1. Right and left deflections are taken at each load by means of the reversing switch or commutator, M, and the power consumed by the load is given by equation (1)[1].

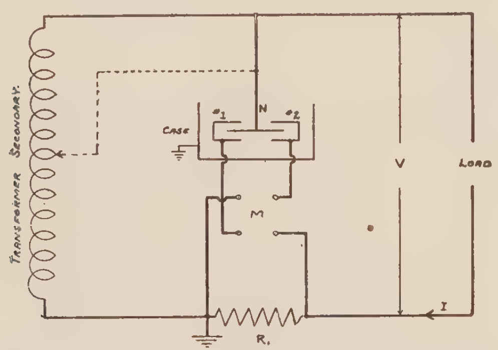

FIG. 1—QUADRANT ELECTROMETER WATTMETER

$$I\,V\cos\varphi = \frac{1 + R\left(\dfrac{V}{n}\right)^2}{2\,b_1\,R_1}\,n\,(\beta - \alpha) - \frac{2-n}{2}\,I^2 R_1 \qquad (1)$$

Where

I = Load current in amperes

V = Load voltage in volts

$\cos\varphi$ = Power factor of the load

R_1 = Value of the non-inductive resistance in ohms

n = The factor by which the voltage applied to the needle must be multiplied to give the load voltage V

α = Deflection of the electrometer with the commutator vertical

β = Deflection of the electrometer with the commutator horizontal

R = An electrometer constant called the needle constant

b_1 = An electrometer constant

The quadrant electrometer wattmeter may be used as a deflection instrument as described above, or it may be used as a zero instrument by a method developed by Simons and Brown[2]. Simons and Brown showed that the deflection may be reduced to zero by the insertion of a resistance in the needle circuit of the instrument. The insertion of the proper value of resistance enables one to bring the voltage applied to the needle in quadrature with the voltage drop across the resistance R_1 and thereby reduce the deflection to zero. The power factor of the load may then be calculated from equation (2)[2].

$$r_2\,c_2\,\omega = \cos\varphi + \frac{2-n}{2}\,\frac{I\,R_1}{V} \qquad (2)$$

Where

r_2 = The resistance inserted in the needle circuit

c_2 = The capacity of the needle circuit

f = Frequency

$\omega = 2\,\pi\,f$

and the other symbols have the same meanings as those used in equation (1).

The zero method of Simons and Brown possesses certain limitations, as pointed out by them,[3] on capacity loads of low power factor where n is large. This method is difficult to use on loads of high power factor because of the large value of resistance required for insertion in the needle circuit, and is not applicable to inductive

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1. For references see bibliography appended.

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circuits unless the needle voltage is reduced to a small fraction of the load voltage.

I. Theoretical

Zero or balance methods are in general more accurate than deflection methods, and their advantages are too well known to require discussion here. This paper describes a new zero method of measuring power and power factor with the quadrant electrometer. The method is applicable to inductive, resistance, and capacity loads and is independent of the value of the fractional part ($1/n$) of the load voltage applied to the needle.

The zero method described here depends upon the use of continuous potentials to reduce the deflection of the electrometer to zero. A continuous potential is applied to the needle in addition to the a-c. load voltage and a second continuous potential is introduced into the quadrant circuit in addition to the drop across the resistance R_1, caused by the alternating-load current. The polarity of these two continuous potentials is arranged so that their effect opposes the deflection caused by the alternating potentials applied to the needle and quadrants respectively. The deflection is reduced to zero by adjusting the value of the continuous potentials to the proper value. The advantage of the method lies in its simplicity.

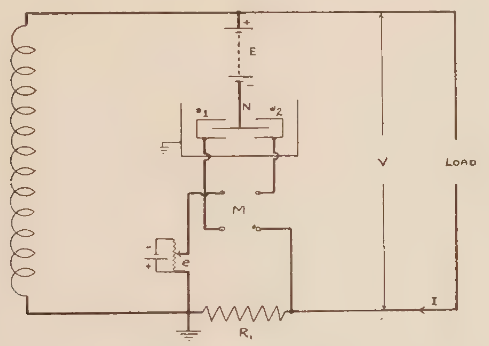

Fig. 2—Connections for Zero Method *A*

A number of arrangements of the connections for introducing the continuous potentials into the circuits of the electrometer have been investigated. Three of these arrangements, called, *A*, *B*, and *C*, respectively, are described in the paper.

Zero Method A. The diagram of connections for zero method *A* is given in Fig. 2, where E equals the continuous potential introduced into the needle circuit of the electrometer and e is the continuous potential introduced into the quadrant circuit; V and I represent the a-c. voltage and current, respectively, and R_1 is the non-inductive resistance.

Three methods of reducing the deflection caused by the a-c. load present themselves; (1) vary both E and e; (2) vary E, e constant; (3) vary e, E constant. Theoretically it makes no difference by which of these methods zero deflection is obtained, but from practical considerations it is simplest to vary e, which is on the grounded side of the instrument, keeping E in the high potential side constant. The variation in e is obtained by using a potentiometer rheostat as shown in Fig. 2.

In making a measurement, two readings are taken in order to eliminate certain electrometer constants. The operation is as follows: Assume that the commutator M is in a vertical position, and that the a-c. circuit is closed. As the instrument begins to deflect, the value of the continuous potential e is adjusted by means of the potentiometer until the deflection equals zero. The value of the potential E and of e_1 are noted. Then the commutator is placed in a horizontal position and the torque due to the a-c. power is again balanced by adjusting the continuous voltage applied to the quadrants. Let e_2 equal the value of the continuous quadrant voltage under these conditions. The experimental results show that the two values of the quadrant continuous potentials, e_1 and e_2, are very nearly equal and, in the equations, the average value e is used without introducing any appreciable error.

Before shifting the commutator from a vertical to a horizontal position, the a-c. circuit and the battery circuit of quadrant voltage, e are opened. This prevents the electrometer needle from deflecting excessively and reduces the time between readings.

Equation (**3**) gives the general equation of the electrometer which was derived by Kouwenhoven in a previous paper.

$$(1 + R\,V_0^2)\,\theta = -\frac{b_1}{2}V_1^2 + \frac{b_1}{2}V_2^2 + b_1 V_0 V_1 - b_1 V_0 V_2 + c_0 V_0 + c_1 (V_1 - V_2) \tag{3}$$

Here

V_0 = The instantaneous value of the voltage applied to the needle.

V_1 = The instantaneous value of the voltage applied to the quadrant pair No. 1

V_2 = The instantaneous value of the voltage applied to quadrant pair No. 2.

θ = Resulting deflection $(\alpha - \beta)$

α = Deflection with the commutator vertical

β = Deflection with the commutator horizontal

R = Needle constant of the electrometer

b_1, c_0 and c_1 = Electrometer constants

Let v equal the instantaneous value of the load voltage V, and i equal the instantaneous value of the load current I; then with the commutator vertical, we have

$$V_0 = v + i\,R_1 - E$$
$$V_1 = -\,e_1$$
$$V_2 = i\,R_1$$

With the commutator horizontal, the values of V_0, V_1 and V_2 are

$$V_0 = v + i\,R_1 - E$$
$$V_1 = i\,R_1$$
$$V_2 = -\,e_2$$

Substituting these values of V_0, V_1 and V_2 in the general electrometer equation (3) and solving, we obtain

equation (8), the derivation of which is given in the mathematical part of the paper.

$$I\,V\cos\varphi + \frac{I^2 R_1}{2} = \frac{E\,e - \dfrac{e^2}{2}}{R_1} - k\,.\,\frac{e}{R_1} \qquad (8)$$

where k is an electrometer constant with a value of $\dfrac{c_1}{b_1}$ as shown in the mathematical part of the paper.

The term, $\dfrac{I^2 R_1}{2}$, of equation (8) is a correction term and equals half the loss in the resistance, R_1, which is measured by the electrometer.

If the polarities of the batteries E and e are reversed with respect to those shown in Fig. 2, we find that the power consumed by the load is given by equation (9).

$$I\,V\cos\varphi + \frac{I^2 R_1}{2} = \frac{E\,e - \dfrac{e^2}{2}}{R_1} + k\,\frac{e}{R_1} \qquad (9)$$

Equations (8) and (9) involve only the single electrometer constant, k. The other electrometer constants, that must be determined if the instrument is to be used as a deflection wattmeter, are eliminated.

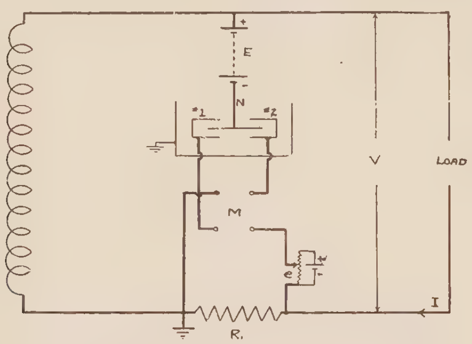

FIG. 3—CONNECTIONS FOR ZERO METHOD *B*

A study of equations (8) and (9) show that this constant k may be eliminated if we take the mean of two sets of readings. The first set being taken with the connections as shown in Fig. 2, and the second set with the batteries E and e reversed. The constant k, however, can be evaluated very easily as shown in the experimental part of the paper, and the value of the term $k\,\dfrac{e}{R_1}$ determined in each case.

Equations (8) and (9) were checked experimentally and the results are given in the experimental part of the paper.

Zero Method B. The diagram of connections for zero method B is given in Fig. 3. Two readings are taken for this connection also, in the first the commutator is vertical, and in the second horizontal. When the commutator is vertical

$$V_0 = v + i\,R_1 - E$$
$$V_1 = 0$$

and

$$V_2 = i\,R_1 + e_1$$

With the commutator horizontal, V_0 has the same value as before, but now

$$V_1 = i\,R_1 + e_2$$

and

$$V_2 = 0$$

Proceeding as in connection A, we find that the power consumed by the load is given by equation (12) which is derived in the mathematical part of the paper.

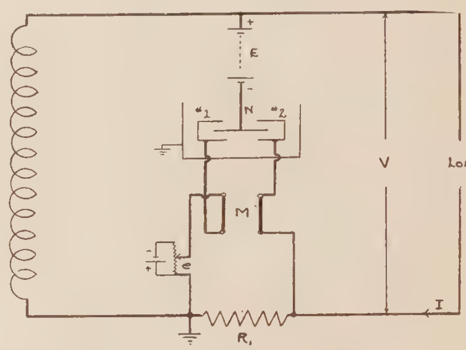

FIG. 4—CONNECTIONS FOR ZERO METHOD *C* COMMUTATOR VERTICAL

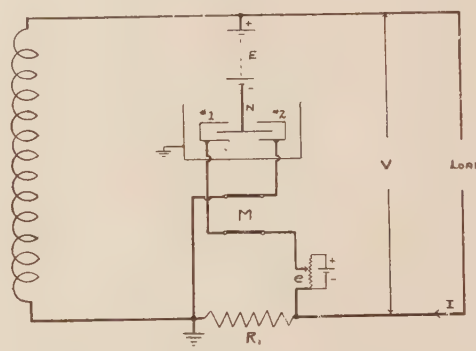

FIG. 5—CONNECTIONS FOR ZERO METHOD *C* COMMUTATOR HORIZONTAL

$$I\,V\cos\varphi + \frac{I^2 R_1}{2} = \frac{E\,e + \dfrac{e^2}{2}}{R_1} - k\,\frac{e}{R_1} \qquad (12)$$

Reversing the batteries E and e, we obtain

$$I\,V\cos\varphi + \frac{I^2 R_1}{2} = \frac{E\,e + \dfrac{e^2}{2}}{R_1} + k\,\frac{e}{R_1} \qquad (13)$$

Experimental proof of the correctness of equations (12) and (13) is given in the experimental part of the paper.

Zero Method C. The diagrams of connections for zero-method C are given in Fig. 4 and Fig. 5, in which the potentiometers for varying e are not shown.

Zero method C, as may be seen from Fig. 4 and Fig. 5,

is a combination of the two previous zero methods, A and B. A study of equations (**8**) and (**12**) shows that the $\frac{e^2}{2}$ terms are of opposite signs; therefore, this term may be eliminated from the final result by combining the two methods.

In taking a measurement the operation is as follows; with the commutator vertical and the quadrant d-c. voltage in the grounded side of the quadrant circuit,

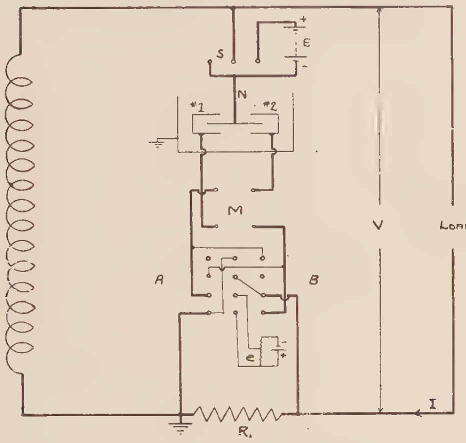

Fig. 6—Switching Arrangement for Zero Methods

as shown in Fig. 4, a balance is obtained between the torque due to the alternating and continuous voltages. Then the commutator is placed horizontally and the quadrant d-c. voltage is thrown to the high side of resistance, R_1, as shown in Fig. 5, and a balance again obtained by adjusting the quadrant continuous voltage.

With the commutator vertical as in Fig. 4, we have

$$V_0 = v + i\,R_1 - E$$
$$V_1 = -\,e$$
$$V_2 = i\,R_1$$

and for Fig. 5

$$V_0 = v + i\,R_1 - E$$
$$V_1 = i\,R_1 + e$$
$$V_2 = 0$$

Substituting these values in the general electrometer equation (**3**) and solving, we obtain (**15**) the derivation of which is given in the mathematical part of the paper

$$I\,V\cos\varphi + \frac{I^2 R_1}{2} = \frac{E\,e}{R_1} - k\,\frac{e}{R_1} \qquad (\mathbf{15})$$

If the polarities of the two batteries E and e are reversed, we get the relation (**16**):

$$I\,V\cos\varphi + \frac{I^2 R_1}{2} = \frac{E\,e}{R_1} + k\,\frac{e}{R_1} \qquad (\mathbf{16})$$

Test data are given in the experimental part of the paper to prove the correctness of equations (**15**) and (**16**).

The battery e may be thrown from one side to the other side of the circuit by means of two double-pole, double-throw switches, or a single, four-pole, double-throw switch, and the connections shown in Fig. 4 and Fig. 5 are combined in a single switching arrangement shown in Fig. 6. It is possible to use zero methods A, B, or C by means of the connections shown in Fig. 6.

A single-pole, double-throw switch, S, is shown in Fig. 6 in the needle circuit. This switch when thrown to the left connects the needle directly to the line and permits bringing the mechanical and electrical zeros into coincidence. When the switch S is thrown to the right the battery E is connected in the needle circuit.

When the four-pole, double-throw switch shown in Fig. 6 is closed on the side marked A, the connections are such as to give zero method A. When closed on the opposite side, B, connections are made for zero method B. For zero method C the four-pole, double-throw switch is closed on side A when the commutator M is vertical and on side B when the commutator is placed horizontal.

Method C eliminates the term $\frac{e^2}{2}$ from the equation and is therefore simpler to use from the standpoint of calculation. We can determine k by taking several electrometer readings in a circuit the loss of which is known. The constant k, is evaluated by this method in the experimental part of this paper, for the quadrant electrometer used in the tests.

It is also evident from equations (**15**) and (**16**) that k may be eliminated if we take the means of two sets of

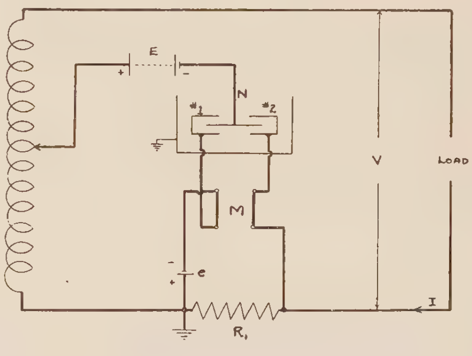

Fig. 7—Fractional Voltage on Needle for Zero Method C Commutator Vertical

readings as described under method A, the first being taken with the polarities of the batteries as shown in Fig. 6, and the second with the batteries reversed.

We can simplify the equations for the purpose of calculation by writing them in a slightly different form. For example we can write equation (**15**) in the form of equation (**17**).

$$I\,V\cos\varphi + \frac{I^2 R_1}{2} = \frac{(E-k)\,e}{R_1} \qquad (\mathbf{17})$$

Zero Method—Fractional Voltage on the Needle. Any one of the three methods described may be used with fractional voltage applied to the needle. Method C requires the least amount of calculation and is probably

the simplest method to use, therefore, it will be the only method discussed with fractional needle voltage. The connections are shown in Figs. 7 and 8.

With the commutator vertical as in Fig. 7, we have

$$V_0 = \frac{v + i\,R_1}{n} - E$$

$$V_1 = -e$$

$$V_2 = i\,R_1$$

and for Fig. 8

$$V_0 = \frac{v + i\,R_1}{n} - E$$

$$V_1' = i\,R_1 + e$$

$$V_2 = 0$$

where n equals the factor by which the a-c. voltage applied to the needle must be multiplied to give the total alternating voltage of the circuit.

Substituting these values in the general equation (3) of the electrometer, and solving, we obtain (**18**) the derivation of which is similar to that of equations (**15**) and (**16**)

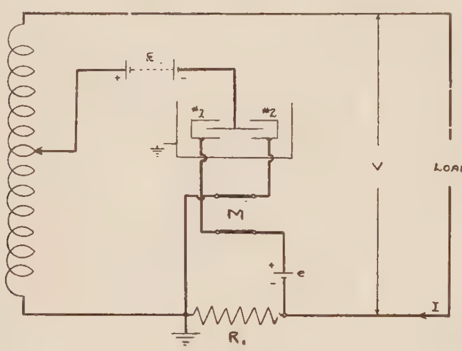

Fig. 8—Fractional Voltage on Needle—Zero Method C Commutator Horizontal

which are derived in the mathematical part of the paper

$$I\,V\cos\varphi + \frac{2-n}{2}\,I^2 R_1 = n\frac{(E-k)\,e}{R_1} \qquad (18)$$

It is evident from a study of equation (**18**) that if n equals 1, it reduces to equation (**17**).

The correctness of equation (**18**) was also verified experimentally.

II. Experimental

The electrometer used in these tests was a Dolezalek quadrant electrometer.

Determination of the Constant, k. The constant, $k = \frac{c_1}{b_1}$, was determined by using a resistance load in the circuit of Fig. 6. The load consisted of a non-inductive resistance, R_0, whose value was 260916 ohms. Method C was used in determining the constant. The applied a-c. voltage was 201 volts at 60 cycles. The continuous voltage, E, that is inserted in the needle lead, was made up of three 22.5-volt Radio B batteries. Its value was measured with a 150-volt d-c. voltmeter. The continuous voltage that is inserted in the quadrant circuit, was taken from a six-volt storage battery connected to a potentiometer rheostat. The value of the continuous quadrant voltage, e, that is actually used in the circuit was measured by a 3/15/150-volt Weston Laboratory Standard d-c. voltmeter. The voltmeters used in the experimental work were checked against a Weston Standard Cell.

The quadrant electrometer was set up and adjusted until its electrical and mechanical zeros coincided. Then the load was applied and readings were taken at different values of R_1, the non-inductive resistance across which the quadrants are connected. Two readings of e were made at each setting of R_1; e_1 with the commutator in a vertical position and e_2 with the commutator in the horizontal position. The value of e was adjusted each time until the deflection was reduced to zero, and e_1 is the value of the quadrant voltage for zero deflection and the commutator vertical, and e_2 for zero deflection and the commutator horizontal.

The readings are given in Table I below:

TABLE I
ZERO METHOD C—RESISTANCE LOAD R_0

A-C. Supply voltage	Load R_0-ohms	R_1 ohms	E volts	Commutator $\|\|$ e_1-volts	Commutator $=$ e_2-volts	Average e volts
201	260916	500	69.4	1.128	1.121	1.1245
		1000	69.45	2.284	2.208	2.246
		2000	69.45	4.63	4.31	4.47
		1000	69.4	2.29	2.20	2.245
		500	69.4	1.127	1.120	1.1235
		1000	69.35	2.284	2.205	2.245
		2000	69.4	4.62	4.32	4.47

The value of the alternating current in the circuit and the total loss measured by the electrometer, which in this case is the loss in the load R_0 plus one-half the loss in R_1, were calculated for each set of readings. From these results the constant, k, was determined from equation (**15**) as shown in Table II. Its value was found to equal 0.8154.

TABLE II
DETERMINATION OF CONSTANT k

Zero-Method C R_1 ohms	$I^2\left(R_0+\frac{R_1}{2}\right)$ Watts calculated	$\frac{E\,e}{R_1}$	Resistance Load R_0: $\frac{Ee}{R_1} - I^2\left(R_0+\frac{R_1}{2}\right) = k\frac{e}{R_1}$	k
500	0.1544	0.1561	0.0017	0.7559
1000	0.1540	0.1560	0.0020	0.8905
2000	0.1531	0.1552	0.0021	0.9395
1000	0.1540	0.1558	0.0018	0.8020
500	0.1544	0.1559	0.0015	0.6673
1000	0.1540	0.1556	0.0016	0.7130
2000	0.1531	0.1552	0.0021	0.9395
			Average,	0.8154

Experimental Proof of Zero Method A. Experimental proof of the correctness of the theory involved in zero method A and of equations (**8**) and (**9**) that apply to

this method was obtained by using a resistance load as described in the determination of the electrometer constant k. The connections shown in Fig. 2 were used in this test, except that the polarity of the two batteries are opposite to that shown in the figure. Therefore, equation (**9**) applies to this test.

The results of the test are given in Table III. The watts consumed by the load R_0 and the loss in the resistance R_1 were calculated from the values used in the circuit as was the case in Table II.

A comparison of the results given in the last two columns of Table III shows good agreement between the calculated watts and the watts as measured by the electrometer.

As stated in the theoretical part of the paper, the constant k need not be determined if two sets of readings are taken, one with the battery polarities as shown in Fig. 2, and the other with the polarities reversed. In order to check this conclusion from the theory a number of sets of readings were taken at different values of R_1, using the resistance load, R_0, of 260916 ohms. The results for two sets of these readings are given in Table IV.

A comparison of the average watts as measured by the electrometer with the calculated watts shows an excellent agreement, and proves that this method may be used if desired to determine watts consumed by a load. A disadvantage of this method lies in the fact that four readings are needed.

In most cases, it is better to determine the electrometer constant k and calculate the power consumed by the load from a single set of readings.

The experimental results prove that Method A and the equations that apply are correct.

Experimental Proof of Zero Method B. The experimental proof of the correctness of the theory of zero Method B and of equations (**12**) and (**13**) was also

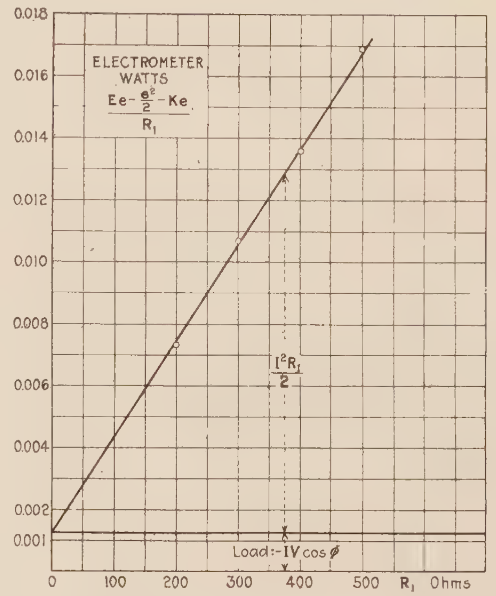

Fig. 9—Capacity Load (Zero B Method)

obtained using a resistance load, R_0. The connections used are those given in Fig. 3, and equation (**12**) applies to this test.

The results of this test are given in Table V and a study of the last two columns show that there is a good

TABLE III

ZERO-METHOD A—RESISTANCE LOAD R_0

A-C. Supply voltage	Load R_0 ohms	R_1 ohms	E volts	Commutator: ‖ e_1 volts	Commutator: = e_2 volts	Average e volts	$I^2\left(R_0+\frac{R_1}{2}\right)$ Watts calculated	Electrometer watts $\dfrac{Ee-\frac{e^2}{2}+ke}{R_1}$
202	260916	100	69.1	0.23	0.216	0.223	0.1563	0.1556
202		500	69.0	1.148	1.112	1.13	0.1559	0.1565
202		1000	69.1	2.318	2.254	2.236	0.1552	0.1538
203		2000	69.0	4.72	4.6	4.66	0.1562	0.1572
203		4000	69.0	9.68	9.42	9.55	0.1544	0.1553

TABLE IV

A-C. SUPPLY VOLTAGE = 203 VOLTS

Remarks Batteries	R_1 ohms	E volts	Commutator: ‖ e_1 volts	Commutator: = e_2 volts	Average e volts	Electrometer Reading: $\dfrac{Ee-\frac{e^2}{2}}{R_1}$	Electrometer Reading: Average watts	Calculated watts $I^2\left(R_0+\frac{R_1}{2}\right)$
As in Fig. 2.....	100	69.1	0.298	0.16	0.229	0.1582	0.1575	0.1578
Reversed......	100	69.1	0.31	0.144	0.227	0.1568		
As in Fig. 2.....	2000	69.0	4.81	4.64	4.725	0.1574	0.1564	0.1562
Reversed......	2000	69.0	4.72	4.6	4.66	0.1554		

agreement between the calculated watts and the watts as measured by the electrometer.

The experimental results prove the correctness of the theory involved in Method B.

Experimental Proof of Zero Method C. Experimental proof of zero method C follows from the results of the tests of methods A and B and also from the measurements made to determine the value of the constant k which are given in Tables I and II. Therefore, no further readings will be given for the measurement by method C of the power consumed in a resistance load.

Capacity Load. Tests were made to determine the loss in a condenser using zero methods A, B and C. The condenser used in these tests was a 1/10 microfarad standard mica condenser. The results obtained by the three methods checked closely, and are given here for methods B and C only.

Data taken by method B, using the connections of Fig. 2, are given in Table VI.

TABLE V
ZERO METHOD B, RESISTANCE LOAD R_0

A-C. Supply voltage	Load R_0 ohms	R_1 ohms	E volts	Commutator $\vert\vert$ e_1 volts	Commutator $=$ e_2 volts	Average e volts	Calculated watts $I^2\left(R_0+\frac{R_1}{2}\right)$	Electrometer watts $\frac{E\,e+\frac{e^2}{2}-k\,e}{R_1}$
201	260916	500	69.35	1.12	1.111	1.115	0.1544	0.1541
		1000		2.208	2.20	2.204	0.1540	0.1535
		2000		4.33	4.31	4.32	0.1531	0.1527
		1000		2.214	2.192	2.203	0.1540	0.1535

TABLE VI
CAPACITY LOAD, ZERO-METHOD B
A-C. Applied Voltage = 199 Volts at 61 cycles

R_1 ohms	E volts	Commutator $\vert\vert$ e_1 volts	Commutator $=$ e_2 volts	Average e volts	Electrometer reading $\frac{E\,e+\frac{e^2}{2}-k\,e}{R_1}$ = watts
200	69.0	0.016	0.027	0.0215	0.00733
300		0.044	0.05	0.047	0.01069
400		0.079	0.08	0.0795	0.01356
500		0.13	0.118	0.124	0.01692

In order to eliminate the correction term $\frac{I^2 R_1}{2}$ the electrometer[4] watts are plotted against the values of R_1 as abscissas. These points lie on a straight line as shown in Fig. 9. If this line is extended to the ordinate axis it will cut the axis at a value equal to the watts lost in the load.[5] From Fig. 9 we see that the loss in the condenser is 0.00125 watts.

A test was made with the same condenser using method C. In this test the loss in the condenser was calculated from the formula

$$I\,V\cos\varphi = \frac{(E-k)\,e}{R_1} - \frac{I^2 R_1}{2}$$

The current I equaled 0.00754 amperes as calculated from the constants of the circuit. The readings are given in Table VII and the average loss was found to equal 0.00127 watts and the power factor was 0.085 per cent. The results of the tests by the two methods are in close agreement.

TABLE VII
CAPACITY LOAD, ZERO-METHOD C
A-C. Applied Voltage = 200 Volts at 60 Cycles

R_1 ohms	E volts	Commutator $\vert\vert$ e_1 volts	Commutator $=$ e_2 volts	Average e volts	Electrometer watts $\frac{(E-k)\,e}{R_1}$	$\frac{I^2 R_1}{2}$ watts	Watts loss in condenser
200	69.0	0.023	0.018	0.0205	0.00698	0.00569	0.00129
300		0.05	0.036	0.043	0.00977	0.00853	0.00124

TABLE VIII
A-C. Applied Voltage = 62 Volts at 60 Cycles

Method	R_1 ohms	E volts	Average e volts	$E\,e$	$\frac{e^2}{2}$	$k\,e$	Electrometer reading. (Loss in Inductance plus $\frac{I^2 R_1}{2}$)
A	200	69	1.707	117.8	−1.456	−1.392	0.575
B	200		1.6695	115.2	+1.393	−1.361	0.576
C	200		1.6955	117.0	0	−1.382	0.578

Inductive Load. Readings were taken with an inductive load using all three zero methods. The load consisted of an inductance of about 8. henrys and 1650 ohms resistance.

In this test the polarity of the batteries was such that equation (**8**) applies to the results of method A; equation (**12**) to method B; and equation (**15**) to method C.

The results are given in Table VIII and the loss as calculated includes half the loss in the shunt resistance R_1, which was the same for each method.

A comparison of the results of the three methods given in the last column of Table VIII shows that they give the same loss for the circuit within $\pm$ 0.3 per cent.

The experimental results prove conclusively the correctness of the equations as derived, and that the methods may be employed to measure the loss at any value of the power factor leading or lagging.

III. Mathmetical

Derivation of Equation (**8**) *Method A.* Equation (**8**) is obtained by substituting the instantaneous values of the potentials applied to the needle and quadrants in the general equation (**3**) of the electrometer. The electrometer reads the integral of these voltages over a complete period T.

With the commutator vertical in Fig. 2 we have

$$V_0 = v + i R_1 - E$$
$$V_1 = - e_1$$
$$V_2 = i R_1$$

where $v = \sqrt{2}\, V \sin \omega t$

and $i = \sqrt{2}\, I \sin(\omega t \pm \varphi)$

Substituting these values and integrating over a complete period, we get the values of the terms in equation (**3**) as follows:

$$-\frac{b_1}{2} V_1^2 = -\frac{b_1}{2} e_1^2$$

$$+\frac{b_1}{2} V_2^2 = +\frac{b_1}{2} \frac{1}{T} \int_0^T R_1^2 . 2 I^2 \sin^2(\omega t \pm \varphi)\, dt = +\frac{b_1}{2} I^2 R_1^2$$

$$+ b_1 V_0 V_1 = + b_1 \frac{1}{T} \int_0^T [\sqrt{2}\, V \sin \omega t + R_1 \sqrt{2}\, I \sin(\omega t \pm \varphi) - E][- e_1]\, dt = + b_1 E e_1$$

$$- b_1 V_0 V_2 = - b_1 \frac{1}{T} \int_0^T [\sqrt{2}\, V \sin \omega t + R_1 \sqrt{2} I \sin(\omega t \pm \varphi) - E][R_1 \sqrt{2} I \sin(\omega t \pm \varphi)]\, dt = - b_1 (R_1 I V \cos \varphi + I^2 R_1^2)$$

$$+ c_0 V_0 = c_2 \frac{1}{T} \int_0^T [\sqrt{2}\, V \sin \omega t + R_1 \sqrt{2}\, I \sin(\omega t \pm \varphi) - E]\, dt = - c_0 E$$

$$+ c_1 V_1 = - c_1 e_1$$

$$- c_1 V_2 = - c_2 \frac{1}{T} \int_0^T \sqrt{2}\, V \sin \omega t\, dt = 0$$

With the commutator horizontal the values of V_1 and V_2 change as stated under zero method A, and by substituting these new values of V_1 and V_2 in the terms of equation (**3**) and integrating we may determine the values of these terms for the commutator horizontal.

The signs and the values of the terms in equation (**3**) for the two positions of the commutator are given below in (**4**) and (**5**).

Pos of Comm.	Equa. No.	VALUE OF TERMS				
	(3)	$-\frac{b_1}{2} V_1^2 + \frac{b_1}{2} V_2^2$	$+ b_1 V_0 V_1$	$- b_1 V_0 V_2$	$+ c_0 V_0 + c_1 V_1 - c_1 V_2$	$= (1 + R V_0^2)\, \theta$
$\vert\vert$	(4)	$-\frac{b_1}{2} e_1^2 + \frac{b_1}{2} I^2 R_1^2$	$+ b_1 E e_1$	$- b_1 (R_1 I V \cos \varphi + I^2 R_1^2)$	$- c_0 E - c_1 e_1 - 0$	$= (1 + R V_0^2)\, \alpha$
=	(5)	$-\frac{b_1}{2} I^2 R_1^2 + \frac{b_1}{2} e_2^2$	$+ b_1 (R_1 I V \cos \varphi + I^2 R_1^2)$	$- b_1 E e_2$	$- c_0 E - 0 + c_1 e_2$	$= (1 + R V_0^2)\, \beta$

Taking the algebraic sum of equations (**4**) and (**5**) we get equation (**6**).

$$(1 + R V_0^2)(\beta - \alpha) = 2 b_1 R_1 I V \cos \varphi + b_1 I^2 R_1^2 - b_1 E (e_1 + e_2) + \frac{b_1}{2} (e_1^2 + e_2^2) + c_1 (e_1 + e_2) \qquad (6)$$

The experimental results show that e_1 and e_2 are nearly equal and that we may write $e = \frac{e_1 + e_2}{2}$ without introducing any appreciable error. Since the deflections α and β are each zero, we may write equation (**6**) equal to zero and solve for the power consumed by the load.

$$I V \cos \varphi + \frac{I^2 R_1}{2} = \frac{E e - \frac{e^2}{2}}{R_1} - \frac{c_1}{b_1} \frac{e}{R_1} \qquad (7)$$

Equation (**7**) contains two of the electrometer constants b_1 and c_1, which may be combined as previously described, in a single constant $k = \frac{c_1}{b_1}$. Under these

conditions we may write equation (**7**) in the form

$$I\,V\cos\varphi + \frac{I^2 R_1}{2} = \frac{E\,e - \dfrac{e^2}{2}}{R_1} - k\frac{e}{R_1} \qquad (8)$$

If we reverse the polarities of the two batteries, E and e, and proceed as in determining equation (**8**) we find that the power consumed by the load is given by equation (**9**).

$$I\,V\cos\varphi + \frac{I^2 R_1}{2} = \frac{E\,e - \dfrac{e^2}{2}}{R_1} + k\frac{e}{R_1} \qquad (9)$$

Derivation of Equation (**12**), *Method B.* The relations giving the power consumed by the load with the connections as in Fig. 3, method B, are derived from equation (**3**) in a manner similar to that used in finding (**8**). The elimination of this term may be accomplished in method C, for example, by reversing the polarity of the battery in the needle circuit, instead of reversing e as described under this method. This, however, introduces another correction term in the equation which involves E and is, therefore, not to be recommended.

The importance of the correction term, $k\dfrac{e}{R_1}$, can be reduced by use of larger values of the needle battery E. This reduces the value of e needed to balance the torque of the a-c. voltages.

IV. Errors

The sources of error present in any quadrant electrometer have already been ably discussed in an Institute paper[2]. The more important are:

Pos. of Comm.	Equa. No.	VALUE OF TERMS
	(3)	$-\dfrac{b_1}{2}V_1^2 + \dfrac{b_1}{2}V_2^2 + b_1 V_0 V_1 - b\ \ V_0 V_2 + c_0 V_0 + C_1 V_1 - c_2 V_2 \quad = (1 + R\,V_0^2)\,\theta$
$\vert\,\vert$	*(10)*	$0 + \dfrac{b_1}{2}(I^2 R_1^2 + e_1^2) + 0 - b_1(R_1 I\,V\cos\varphi + I^2 R_1^2 - E\,e_1) - c_0 E - 0 - c_1 e_1 \quad = (1 + R\,V_0^2)\,\alpha$
=	*(11)*	$-\dfrac{b_1}{2}(I^2 R_1^2 + e_2^2) + 0 + b_1(R_1 I\,V\cos\varphi + I^2 R_1^2 - E\,e_2) - 0 - c_0 E + c_1 e_2 - 0 \quad = (1 + R\,V_0^2)\,\beta$

Taking the algebraic sum of equations (**10**) and (**11**) and solving for the power consumed by the load we obtain equation (**12**) for connection B.

$$I\,V\cos\varphi + \frac{I^2 R_1}{2} = \frac{E + \dfrac{e^2}{2}}{R_1} - k\frac{e}{R_1} \qquad (12)$$

Derivation of Equation (**15**), *Method C.* Method C is a combination of methods A and B, as stated above. With the commutator vertical equation (**4**) of method A, holds and with the commutator horizontal we have equation (**10**) of method B. Taking the algebraic sum of equations (**10**) and (**4**) we obtain equation (**14**).

$$(1 + R\,V_0^2)(\beta - \alpha) = 2\,b_1 R_1 I\,V\cos\varphi$$

$$+ b_1 I^2 R_1^2 - b_1 E(e_1 + e_2) + \frac{b_1}{2}(e_1 - e_2) + c_1(e_1 + e_2) = 0 \qquad (14)$$

Assuming that e_1 is very nearly equal to e_2 the fourth term of the equation becomes negligible and we can write that the power consumed by the load is

$$I\,V\cos\varphi + \frac{I^2 R_1}{2} = \frac{E\,e}{R_1} - k\frac{e}{R_1} \qquad (15)$$

The Correction Term, $k\dfrac{e}{R_1}$. Several methods are possible for eliminating the correction term, $k\dfrac{e}{R_1}$ in addition to those mentioned in the paper. The

1. A study of the diagram of connections of the quadrant electrometer shows that the electrostatic capacity formed by the two quadrant pairs and their leads is in parallel with the non-inductive resistance R_1. Therefore, the drop across R_1 and this condenser in parallel with it will not be in phase with the current. This error is naturally greater the higher the value of R_1. Taking this into account we find that the equation[6] for method C is as follows:

$$I\,V\cos\varphi + \frac{2 - n}{2}I^2 R_1 + I(\omega\,c_1 R_1)\,V\sin\varphi$$

$$= \frac{n(E - k)\,e}{R_1} \qquad (19)$$

where c_1 is the electrostatic capacity of the quadrant pair circuit in farads.

In measuring the loss in the 1/10 microfarad condenser by methods B and C it was found possible to work with a value of R_1 as low as 200 ohms and still obtain good accuracy. Tests of this same condenser by the deflection method require a value of R_1 of the order of 1000 ohms to obtain satisfactory deflections. It is evident that the error introduced by the capacity of the quadrants depends upon the value of R_1, and that it is reduced in amount by the use of this zero method.

2. Further study of the quadrant electrometer circuit shows that the charging current I_1 from the

needle to the high quadrant flows through R_1 in addition to the load current, I.

This source of error is very small in low voltage electrometers and may usually be neglected.

3. The theory of the electrometer is based upon the assumption that the resistance of the needle circuit is zero, and the needle charging current flows through a pure capacity.

The use of the battery, E, in the needle circuit introduces a resistance, but its value in our tests was so small compared to the capacitance of the needle circuit that its effect was negligible.

4. If fractional voltage is applied to the electrometer needle, the e. m. f. of the portion of the transformer winding to which the needle circuit is attached, may differ in phase from the total voltage in the circuit. This source of error may become very important at low values of the power factor of the load, and in such cases must be corrected for[2].

References

1. Kouwenhoven, "The Quadrant Electrometer," JOUR. A. I. E. E., Sept., 1925, p. 973.

2. Simons and Brown, "The Quadrant Electrometer for Measurement of Dielectric Loss," TRANS. A. I. E. E., Vol. 43, 1924, p. 311.

3. Simons and Brown, "The Quadrant Electrometer for Measurement of Dielectric Loss," TRANS. A. I. E. E., Vol. 43, 1924, p. 313.

4. Orlich, *Ztsch. f. Instrumentin Kunde*, Vol. 29, 1909, p. 33.

5. Whitehead, "Gaseous Ionization in Built-Up Insulation," TRANS. A. I. E. E., Vol. 42, 1923, p. 921.

6. Kouwenhoven, "The Quadrant Electrometer," [Equation (47)]. Paper presented before the Annual Convention of the A. I. E. E., at Saratoga Springs, June, 1925.

General Theory of the Auto-Transformer

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Synopsis.—*The method of complex quantities lends itself admirably to the development of general theory of the auto-transformer. As worked out, in this instance, it is found desirable to maintain the actual voltage ratio instead of reducing values to an equivalent 1:1 basis. Examples are given of calculations by this method, and also comparison is made with calculated performance of the two-circuit transformer. Certain inherent peculiarities of the auto-transformer are pointed out, being due to the effects of internal resistance and reactance.*

Part II is an application of the theory to transformers without iron and a number of interesting conclusions are brought out.

* * * * *

An auto-transformer may be represented as a single winding on an iron core, as illustrated in Fig. 1. Primary voltage, E_1, is impressed on the winding, and secondary voltage, E_2, is obtained by suitable taps. The primary current, I_1, flows in a portion of the winding of t_1 turns. The rest of the winding carries current, I_2, which is the resultant of the current I_1 and the load current I_L, and it consists of t_2 turns. The total turns of the entire winding are $t = t_1 + t_2$. Ratio of transformation is given by

$$f = \frac{t}{t_2} = \frac{t_1 + t_2}{t_2} = \frac{E_1}{E_2}$$

at no load.

Resistances of windings t_1 and t_2 are r_1 and r_2 respectively, and reactances are x_1 and x_2. Fig. 2 illustrates the vector relations which exist. We may begin with the flux ϕ, drawn vertically upward. This is produced by magnetizing current i_m in phase with it. Ninety deg. ahead of the flux is the core-loss current i_c. i_m and i_c vectorially added give the exciting current I_x. Ninety deg. behind the flux is the e. m. f., e_i, induced in the turns t_2. The load current $I_L = i_L + j\, i_L'$ is drawn at any desired angle with reference to e_i.

So far, the vector relations are similar to those of the ordinary two-circuit, constant potential transformer. But in the case of the auto-transformer a departure from similarity occurs at this point. This departure is due to two causes; (1) the current in the turns t_2 is not the load current, and (2) the vectors are given actual values and are not reduced to a 1 : 1 equivalent ratio. This latter consideration is not awkward on account of the fact that auto-transformer ratios do not usually depart very far from 1 : 1, being in that respect quite different from two-circuit transformers.

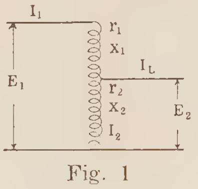

Fig. 1

We now draw $-f\, e_i$, 180 deg. ahead of e_i, and this is that portion of the impressed voltage required to produce e_i in t_2. Similarly, $-\dfrac{I_L}{f}$ is the load component of primary current, 180 deg. ahead of I_L.

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The entire primary current I_1 is the vector sum of I_x and $-\frac{I_L}{f}$. The secondary current, I_2 in t_2, is the vector sum of I_1 and I_L. Secondary voltage, E_2, is obtained by subtracting from e_i the $I_2 r_2$ and $I_2 X_2$ drops in turns t_2.

Primary voltage, E_1, is obtained by adding to $-f e_i$ the $I_1 r_1$, $I_1 x_1$, $I_2 r_2$, and $I_2 x_2$ drops, all operations being, of course, vectorial.

The method of complex quantities lends itself readily to this procedure. It is convenient to start with e_i as the zero vector, however, rather than with E_1 or E_2. This makes the use of the method very simple. Certain difficulties which are introduced may be readily provided for. The chief difficulty is in ascribing to the load current a definite, desired phase angle with respect to E_2, as the components of I_L are given with respect to the zero vector e_i. This and other points will appear in the case of examples cited.

The vector equations are as follows:

$$\dot{I}_1 = \dot{I}_x - \frac{\dot{I}_L}{f} = -\frac{i_L}{f} + i_c + j\left(i_m - \frac{i_L'}{f}\right)$$
$$= i_1 + j\, i_1'$$
$$\dot{I}_2 = \dot{I}_1 + \dot{I}_L = i_1 + i_L + j\,(i_1' + i_L') = i_2 + j\, i_2'$$
$$\dot{E}_2 = e_i - \dot{I}_2 z_2 = e_i - i_2 r_2 + i_2' x_2 - j\,(i_2 x_2 + i_2' r_2)$$
$$= e_2 + j\, e_2'$$

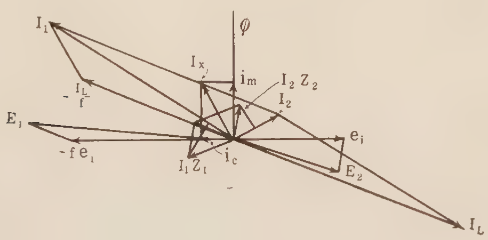

Fig. 2

$$\dot{E}_1 = -f e_i + \dot{I}_1 z_1 + \dot{I}_2 z_2$$
$$= -f e_i + i_1 r_1 - i_1 x_1' + i_2 r_2 - i_2' x_2$$
$$+ j\,(i_1 x_1 + i_1' r_1 + i_2 x_2 + i_2' r_2) = e_1 + j\, e_1'$$

Power input is $P_1 = e_1 i_1 + e_1' i_1'$

Power output is $P_2 = e_2 i_L + e_2' i_L'$

Efficiency is $\eta = \frac{P_2}{P_1}$

Primary power factor is $P f_1 = \frac{P_1}{E_1 I_1}$

Load power factor is $P f_2 = \frac{P_2}{E_2 I_L}$

Regulation is given by the equation

$$\text{Per cent regulation} = \frac{E_2 \text{ at no load} - E_2}{E_2}$$

when the primary impressed voltage is constant. All the above relations, however, are based on an assumed constant induced voltage, e_i, and consequently it would seem, judging by common experience with the two-circuit transformer, that the primary voltage will not be the same at load and no load. It is advisable, then, to determine both E_2 and E_1 for the condition of no load always keeping e_i constant.

The value of E_2 thus obtained should be multiplied by the ratio

$$\frac{E_1 \text{ at load}}{E_1 \text{ at no load}}$$

This reduces E_2 to the value it would have at constant impressed primary voltage. Carrying out this process, equations for the case of $\dot{I}_L = 0$ are as follows:

$$\dot{I}_1 = i_c + j\, i_m = \dot{I}_2$$
$$\dot{E}_2 = e_i - i_c z_2 - j\, i_m z_2 = e_i - i_c r_2 + i_m x_2$$
$$- j\,(i_c x_2 + i_m r_2)$$
$$= e_2 + j\, e_2'$$
$$\dot{E}_1 = -f e_i + i_c (\dot{z}_1 + \dot{z}_2) + j\, i_m (\dot{z}_1 + \dot{z}_2)$$
$$= -f e_i + i_c (r_1 + r_2) + j\, i_c (x_1 + x_2)$$
$$- i_m (x_1 + x_2) + j\, i_m (r_1 + r_2)$$
$$= -f e_i + i_c r_1 + i_c r_2 - i_m x_1 - i_m x_2$$
$$+ j\,(i_c x_1 + i_c x_2 + i_m r_1 + i_m r_2) = e_1 + j\, e_1'$$

$$\text{Per cent regulation} = \frac{K\, E_2 \text{ (at no load)} - E_2 \text{ (at load)}}{E_2 \text{ (at load)}}$$

where

$$K = \frac{E_1 \text{ at load}}{E_1 \text{ at no load}}$$

The value of this constant is either exactly unity or very near to it in practical cases. The difference in voltage between E_1 at load and E_1 at no load is given by the equation

$$\dot{E}_1 \text{ (at load)} - \dot{E}_1 \text{ (at no load)}$$
$$= i_L\left(-\frac{r}{f} + r_2\right) + i_L'\left(\frac{x}{f} - x_2\right)$$
$$+ j\left[i_L\left(-\frac{x}{f} + x_2\right) + i_L'\left(-\frac{r}{f} + r_2\right)\right]$$

where r and x are total resistance $r_1 + r_2$, and total leakage reactance $x_1 + x_2$, respectively.

This difference reduces to zero in many cases, for example, when $f = 2$, $r_1 = r_2$, and $x_1 = x_2$, which is the case with a uniformly wound coil tapped at its middle point.

Thus, in this case, per cent regulation is simply

$$\frac{E_2 \text{ (at no load)} - E_2 \text{ (at load)}}{E_2 \text{ (at load)}}$$

As an illustration of the whole method we will give

values for the calculation of a 50-kva., 60-cycle, 220/110-volt auto-transformer.

Constants, on percentage basis, are as follows:

Induced voltage $= e_i = 1$

$$r_1 = r_2 = 0.01$$
$$x_1 = x_2 = 0.02$$
$$i_m = 0.025$$
$$i_c = -0.01$$
$$f = 2 = \text{ratio of transformation}$$
$$I_L = 1 + j\,0$$

Substituting these values into the above equations we get:

$$I_1 = -0.51 + j\,0.025$$
$$I_2 = 0.49 + j\,0.025$$
$$E_2 = 0.9956 - j\,0.01005$$
$$E_1 = -2.0012 + j\,0.0001$$
$$P_1 = \text{power input} = 1.0206$$
$$P_2 = \text{power output} = 0.9956$$

Efficiency $= 0.974$

Primary power factor $= 0.997$

$$\text{Power factor of load} = \frac{0.9956}{0.9956} = 1$$

To obtain regulation, we have the following values for the condition of zero loading:

$$I_1 = I_2 = -0.01 + j\,0.025$$
$$E_2 = 1.0006 - j\,0.00005$$
$$E_1 = -2.0012 + j\,0.0001$$
$$K = \frac{E_1 \text{ at load}}{E_1 \text{ at no load}} = \frac{2.0012}{2.0012} = 1$$

Therefore,

$$\text{Regulation} = \frac{1.0006 - 0.9956}{0.9956} = \frac{0.005}{0.9956} = 0.005$$

This transformer may be considered as a 1 : 1 two-circuit transformer according to the usual method of calculation. Table I gives comparative performance as auto-transformer and as two-circuit transformer. As transformer of the latter type the constants are:

$$e_i = 1,\ r_1 = r_2 = 0.01,\ x_1 = x_2 = 0.02,\ i_m = 0.05$$
$$i_c = 0.02,\ I_L = 1 + j\,0$$

Values of the components of exciting current are seen to be twice those of the auto-transformer. In general, in order that flux and core-loss shall be the same in the two transformers, it is necessary to divide the values for exciting current of the two-circuit machine by the ratio of transformation of the auto-transformer.

TABLE I

	Two-Circuit Trans.	Auto-Trans.
Load Current	$1 + j\,0$	$1 + j\,0$
Efficiency	0.963	0.974
Regulation	0.022	0.005

Comparative efficiencies are as we should expect. Due to reduction in copper losses the auto-transformer shows superiority. In regulation, however, its superiority is far more marked, due largely to the fact that the impedance drop in the secondary winding has a negative effect and tends to raise the secondary voltage instead of lowering it.

Under short circuit, the exciting current ceases to flow in the secondary turns, and is diverted entirely into the short circuit. The short-circuit current may be considered as made up of three parts, (1) that supplied by the secondary turns, which is the induced voltage divided by secondary impedance, (2) the load component of the primary which is equal to (1) multiplied by $\frac{t_2}{t_1}$, and (3) the exciting current, which, at short circuit, is equal to $\frac{t}{t_1}$ times I_x at no load. In the case considered, in which $f = 2$, it is:

$$I_2 = \frac{e_i}{r_2 + j\,x_2} = \frac{e_i\,r_2}{z_2^2} - j\,\frac{e_i\,x_2}{z_2^2} = 20 - j\,40$$

$$I_{sh.\,cir} = 2\,I_2 + 2\,I_x$$
$$= 40.02 - j\,80.05$$

where I_x is taken as flowing in the same direction as I_2; that is, $I_x = 0.01 - j\,0.025$.

Total short-circuit current is then 89, approximately.

When operated as a two-circuit transformer, the short-circuit current is 22.3, or one-fourth as much as that of the auto-transformer.

It is interesting to notice the conditions as relating to the exciting current with various loadings of the transformer. At no load, its value is the same in both parts of the winding, t_1 and t_2. Exciting ampere-turns are $I_x\,t$. As the load is increased the load impedance offers a path for the exciting current in parallel with t_2, thereby causing a slight increase in the exciting current which flows in t_1 and a slight decrease in that which flows in t_2. No account is taken of this variation for ordinary loading, as it is insignificant. The total exciting ampere-turns remain constant for all loads, producing constant mutual flux and constant induced voltage in the secondary. Voltage induced in t_1 must also be constant. At short circuit, we have maximum exciting current in t_1 and zero exciting current in t_2. In a 2 : 1 transformer the value of this current in t_1 is $2\,I_x$, where I_x is the no-load exciting current.

The total $I_1\,Z_1$ drop in t_1 is approximately equal to e_i, at short circuit, so that the impressed voltage $E_1 = 2\,e_i$. This relationship is similar to that which exists in a two-circuit transformer, where, at short-circuit, the voltage drop in the primary is approximately equal to the induced voltage. In this case, however, the equality is brought about by reduction in the value of the induced voltage, which, at short circuit, is only half its no-load value.

Part II

Auto-Transformers Without Iron[2]

Air-core transformers are in general at a disadvantage owing to the fact that their magnetic fields are produced in a medium of unit permeability. Absence of iron, however, offers some compensating advantages, namely, absence of core-loss and exciting current distortion, and saving in cost of iron and in cost of construction. At sixty cycles, these advantages are far out-weighed by the disadvantages in performance as compared with two-circuit transformers. At higher frequencies the situation becomes more and more favorable for the air-core transformers, until at radio frequencies the use of iron is inadmissible.

With auto-transformers the case is distinctly more favorable for the air-cores at lower frequencies. The same theory applies as with iron-core transformers except that the core-loss component of the exciting current drops out. The constants are, of course, very different and it will be of interest to give some values and results that may be expected in practise. An air-core auto-transformer should be wound for maximum self-inductance of the entire winding and maximum mutual inductance of the two parts, that is, of t_1 and t_2. This maximum mutual inductance will, of course, mean minimum leakage reactance.

An auto-transformer may be designed from either of two points of view as respects operation. It may be designed either to operate at a fixed ratio of transformation or as a compensator with taps to give different voltages over a considerable range of ratio.

Table II gives comparative results to be expected from an air-core compensator with three taps giving voltage ratios of 4 : 3, 4 : 2, and 4 : 1. The same voltage is impressed on the primary in each case, and the same load current is assumed. The constants for the three cases are given in the preceding table.

TABLE II

	A	*B*	*C*
Transformer ratio	4:3	4:2	4:1
Primary resistance, r_1	0.01	0.02	0.03
Secondary resistance, r_2	0.03	0.02	0.01
Primary reactance, x_1	0.1	0.2	0.3
Secondary reactance, x_2	0.3	0.2	0.1
Magnetizing current	0.3	0.3	0.3
Load current	$1-j\,.1$	$1-j\,.1$	$1-j\,.1$
Induced voltage, e_i	1.5	1	0.5
Primary voltage, E_1	2.12	2.12	2.12
Primary current, I_1	0.838	0.61	0.41
Power input	1.5945	1.0642	0.5349
Secondary voltage, E_2	1.575	1.047	0.52
Secondary current, I_2	0.372	0.559	0.783
Power output	1.5833	1.05	0.523
Efficiency	0.992	0.986	0.979
Primary power factor	0.896	0.822	0.614
Load power factor	1 approx	1.	1.
Secondary no-load voltage	1.59	1.06	0.53
Primary no-load voltage	2.12	2.12	2.12
Per cent regulation	0.0095	0.0124	0.0192

It is to be noted that for low ratio, the primary turns are relatively heavily loaded while the secondary turns are lightly loaded.

With high ratio, the opposite is true. Therefore, if the transformer is to be operated continuously at a fixed ratio, the cross section of wire for primary and secondary should be proportioned to the respective currents to be carried. For a 2 : 1 ratio, the wire should be the same in cross-section for both windings.

In the above table, we see, as we saw with the case of the iron-core transformer, that the impressed voltage is constant regardless of load. The effect of $r\,I$ drop in the primary is exactly neutralized by the $r\,I$ drop in the secondary except for the small and constant drop due to the exciting current. This balance of drops does not obtain if the resistances and reactances are not so proportioned as to accomplish it, but there is always a tendency in that direction. To illustrate this situation we will make comparison of two auto-transformers with the following constants: ratio of transformation, 5 : 4; exciting current, 0.3; load current, $I_L = 1 - j\,.2$; induced voltage, 1; total resistance, 0.04; total reactance, 0.4. The resistances and reactances of the two transformers are differently distributed between primary and secondary, as follows:

TABLE III

	D	*E*
Primary resistance, r_1	0.02	0.003
Primary reactance, x_1	0.2	0.03
Secondary resistance, r_2	0.02	0.037
Secondary reactance, x_2	0.2	0.37
Primary current, I_1	0.922	0.922
Secondary current, I_2	0.328	0.328
Primary voltage, E_1	1.41	1.358
Secondary voltage, E_2	1.05	1.093
No-load primary voltage	1.37	1.37
No-load secondary voltage	1.06	1.115
Regulation constant, K	1.03	0.99
Per cent regulation	0.038	0.011

Transformer E is seen to operate at nearly constant impressed voltage, and it is this one in which the wire has been proportioned to the currents to be carried.

Certain inherent features of the performance of air-core transformers are of interest. They are due to the fact that the magnetic field is in a medium of constant permeability and consequently all effects due to magnetic saturation are automatically eliminated.

1. Thus, if the characteristics of an air-core transformer are known for one value of impressed voltage, they may be obtained for any other value. For example, let $E_1 = 100$, and let maximum efficiency occur with a load of 10 amperes, and, let us say, 950

2. A paper on this subject was presented by the author before Section M of the American Association for the Advancement of Science, December 1916, but was preliminary in character and never has been published.

watts. If, now, the voltage is raised to 110, maximum efficiency will occur at $\frac{110}{100}$ times $10 = 11$ amperes, and $\left(\frac{110}{100}\right)^2$ times $950 = 1150$ watts. One efficiency curve applies to the transformer, whatever the impressed voltage, provided the scale of amperes and watts is changed in the proper ratio.

2. To obtain maximum capacity, it is only necessary to impress such a voltage on the primary as will correspond with maximum permissible current in the windings at full load, or, conversely, the windings of a transformer may be so chosen as to carry maximum permissible current at full load with any specified impressed voltage.

3. Regulation of an air-core auto-transformer is more affected by leakage reactance than by resistance, when operating at high power factor. This fact is quite apparent from a study of the vector diagram. The primary $I\,x$ drop is almost directly in phase with the impressed voltage, instead of being at right angles to it, giving nearly the worst condition for regulation. To offset this, however, the secondary $I\,x$ drop, while considerably out of phase with E_2, is generally so directed as to assist regulation, partially neutralizing the bad effects of primary reactance.

(4). Power factor of the air-core transformer is generally much poorer than that of the iron-core type because the magnetizing current is a comparatively large out-of-phase component of the primary current. This large magnetizing current is not altogether undesirable, however. It causes a greater lead of I_2 with respect to E_2 and reduces the amount of I_2 without proportionally increasing I_1.

In general, it may be said that the air-core auto-transformer offers possibilities at 60 cycles. At higher frequencies, such as 120 or 180 cycles, it becomes of decidedly more than theoretical interest.

Variable Armature Leakage Reactance in Salient-Pole Synchronous Machines

BY VLADIMIR KARAPETOFF[1]

Fellow, A. I. E. E.

Synopsis.—*The electrical performance characteristics of a polyphase synchronous machine, that is, its voltage-current relations under load, depend essentially upon the nature and the extent of the magnetomotive forces of the armature currents. Broadly speaking, the effect of these magnetomotive forces is two-fold; i. e., (a) they oppose and distort the field magnetomotive force and (b) they create leakage fields linked with the armature conductors. The first influence is known as the armature reaction, and the second as the armature reactance. More specifically, in a machine with salient poles, the armature reaction may be resolved for purposes of computation into the direct reaction (along the center lines of the poles) and the transverse reaction, midway between the poles. In polyphase machines of usual proportions, the armature leakage reactance, x, usually plays a secondary role, and for most purposes is assumed to be constant and independent of the power factor of the load. The vector of the reactive drop, Ix, is simply drawn in a leading time quadrature with the current I.*

However, in machines with considerable armature reactance, or where higher accuracy is required, the assumption of a constant x leads to noticeable discrepancies between the computed and observed data. This is of particular importance in problems which involve hunting, instability, etc., and in which the torque (or displacement) angle must be predicted. This angle depends to a considerable degree upon the leakage reactance of the machine. It has been previously proposed by others to use two distinct values of leakage reactance, one when the leakage paths around a group or belt of armature slots are closed through the center of a pole face (maximum reactance), and the other when such slots are midway between the poles (minimum reactance). However, no account has been taken apparently of a gradual change in the reactance between the two extreme positions, nor have the results been properly correlated with the rest of the factors which enter in the performance of the machine.

In the present paper, the leakage inductance is assumed to consist of two parts, one of which is constant (the average inductance), and the other varying harmonically at a double frequency, reaches a maximum opposite the centers of the poles. A magnetic linkage equation is written, and its derivative with respect to the time angle is taken to obtain the induced voltage. The result shows that the foregoing assumption leads to two reactive drops, one, the usual average Ix drop and another a supplementary drop, leading Ix by an angle 2 ψ, where ψ is the internal phase angle at which the machine is operating. These quantities are introduced in the usual Blondel diagrams for the generator and the motor, and the relationships among the various quantities are established both graphically and analytically.

In the performance characteristics of synchronous machines with salient poles, there are certain discrepancies between the computed and the measured electrical quantities, even when the usual Blondel diagram is used which is supposed to take into consideration the influence of salient poles on the armature reaction[2]. These discrepancies may be accounted

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2. For a theory of Blondel's diagram, see V. Karapetoff, *The Magnetic Circuit*, Arts. 48 and 49. The subject of direct and transverse armature reaction is also treated in detail in Chaps. 47 and 48 of the author's *Experimental Electrical Engineering*, Vol. II, 3rd ed., now going through the press. Extensive literature references will be found there.

for, at least in part, by taking into consideration the variations in the value of the permeance of the armature leakage flux during a cycle.

At zero power factor of the load, the armature leakage flux reaches a lower maximum value than with the same armature current at unity power factor, because in the latter case the armature slots, in which the current reaches its maximum, are almost opposite the centers of the poles, and the permeance of the leakage paths is greater. Hence, at high values of power factor, the machine should be expected to behave as if its leakage reactance were greater than that obtained from a short-circuit test. Often such is actually the case. Moreover, the torque (or displacement) angle[3] often comes out from test larger than from computation. This also indicates an actual increase in the equivalent reactive drop ix, as would be expected theoretically at higher values of power factor.

Several authors have pointed out the fact that the armature leakage reactance varies during the cycle, and some have used *two values of reactance*, one opposite the poles, the other midway between the poles[4]. However, to the writer's knowledge, *gradual changes* in the reactance have not as yet been considered quantitatively in their effect upon the Blondel diagram, and the latter is usually drawn with a constant ix drop. An attempt is made below to develop a method whereby such cyclic variations in the reactance can be taken into consideration in Blondel's theory of two armature reactions. Of course, a similar correction could be applied to the less accurate Potier diagram, but it would seem hardly logical to correct for the effect of salient poles upon the leakage reactance in a diagram in which the effect of salient poles on the armature reaction is disregarded altogether.

I. Average Reactance and Supplementary Reactance

In Fig. 1, the curve $A\,B\,C\,D\,E$ represents values of the armature leakage inductance plotted with reference to the axis of abscissas $X\,X$. The time angle is denoted by α, where

$$\alpha = 2\,\pi\,f\,t = \omega\,t \qquad (1)$$

t being time and f the frequency. When $\alpha = 0$, let the group of armature conductors under consideration be opposite the center of a pole. The tooth-tip leakage is then at a maximum, and hence the leakage inductance reaches its maximum value. When $\alpha = 90$ deg., the same group of conductors is midway between the poles and the leakage inductance is a minimum.

Thus, the leakage inductance varies at twice the frequency of the main induced voltage of the machine, and, as a first approximation, the inductance curve in this discussion will be assumed to be a sine wave of double frequency. Even when an actual test gives a curve departing from a sine wave, this experimental curve can be replaced by an equivalent sine wave, because higher harmonics in the inductance can produce only higher harmonics in the terminal voltage or in the current of the machine, and in this paper only the quantities of fundamental frequency are considered. The variable value of inductance, L_α, at an instant of time corresponding to the electrical angle α, shall therefore be expressed as

$$L_\alpha = L + \Delta\,L \cos 2\,\alpha \qquad (2)$$

Here L is the *average* value of the inductance over a cycle, and $\Delta\,L$ is the greatest departure from the average, that is, the amplitude of the sine wave with respect to the axis $X'\,X'$.

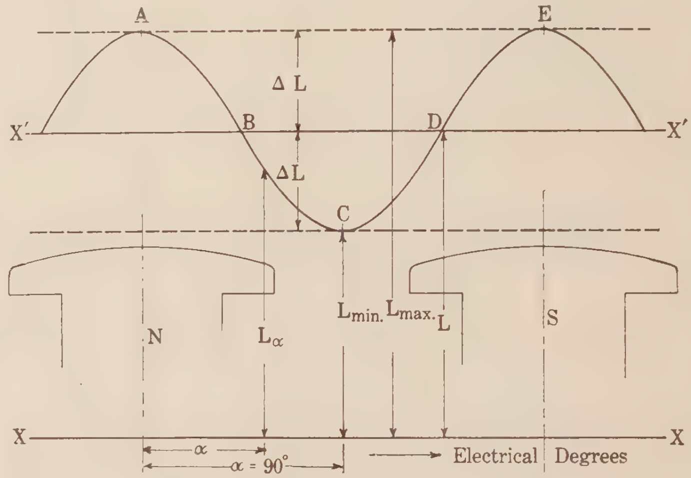

Fig. 1—Variable Armature Leakage Inductance L_α and Its Average Value L

Assuming the armature current to be sinusoidal, it can be written in the form

$$i_\alpha = I \operatorname{Cos}(\alpha - \psi) \qquad (3)$$

where I is the amplitude of the current, and $\psi = Q\,O\,G$, Fig. 2, is the internal phase angle at which the machine is operating. The angle ψ characterizes the interval of time between the instant when a group of armature conductors is opposite the center of a pole and the instant when the current in the same group of conductors reaches a maximum[5]. For a generator, ψ is assumed to be positive when the current reaches a maximum *after* the corresponding group of conductors has passed by the center of a pole (although the current may be leading with respect to the terminal voltage). In a motor, ψ is greater than 90 deg., and may even be greater than 180 deg. when the motor is under-excited. Thus, in equation (3), the case of $\psi = 0$ corresponds to the generator working at such a power factor that the current I reaches its maximum when that group of

3. Mag. Cir., the angle $\beta + \phi_z$ in Fig. 40; this angle is denoted by θ in Fig. 2 of this paper.

4. See, for example, C. P. Steinmetz, *A-C. Phenomena*, Chapter on Armature Reactions in Alternators.

5. *The Magnetic Circuit*, pp. 154 and 155; the angle ψ is marked in the diagrams there.

conductors, through which I is flowing, is directly opposite the center of a pole. It can be shown that under these conditions the current is slightly leading with respect to the terminal voltage, but this fact is of no particular importance in this discussion.

Multiplying equations (**2**) and (**3**) term by term, in order to obtain the instantaneous magnetic linkages, gives,

$$i_\alpha L_\alpha = L\,I\,\mathrm{Cos}\,(\alpha - \psi) + \Delta\,L\,I\,\mathrm{Cos}\,2\,\alpha\,\mathrm{Cos}\,(\alpha - \psi) \qquad (4)$$

In the last term, the product of the cosines can be replaced by their sum and difference. Namely

$$\mathrm{Cos}\,2\,\alpha\,\mathrm{Cos}(2\,\alpha - \psi) = 0.5\,\mathrm{Cos}(\alpha + \psi) + 0.5\,\mathrm{Cos}(3\,\alpha - \psi)$$

Leaving only the fundamental term containing α, and

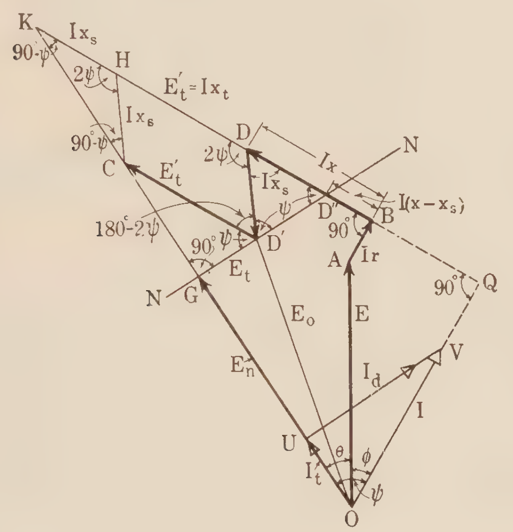

Fig. 2—A Modified Blondel Diagram of a Synchronous Generator with the Average Reactive Drop, Ix, and Supplementary Reactive Drop, Ix_s

disregarding the term with $3\,\alpha$ (the third harmonic), *approximately*,

$$i_\alpha L_\alpha = L\,I\,\mathrm{Cos}\,(\alpha - \psi) + 0.5\,\Delta\,L\,I\,\mathrm{Cos}\,(\alpha + \psi) \qquad (5)$$

The voltage drop due to these linkages is

$$e_x = d\,(i_\alpha L_\alpha)/d\,t = \omega\,d\,(i_\alpha L_\alpha)/d\,\alpha \qquad (6)$$

Hence, taking a derivative of equation (**5**),

$$e_x = -\,\omega\,L\,I\,\mathrm{Sin}\,(\alpha - \psi) - 0.5\,\omega\,\Delta\,L\,I\,\mathrm{Sin}\,(\alpha + \psi) \qquad (7)$$

The term $-\,\omega\,L\,I\,\mathrm{Sin}\,(\alpha - \psi)$ represents a sine voltage which leads the current wave by 90 deg. and corresponds to the average constant reactance

$$x = \omega\,L \qquad (8)$$

such as ordinarily used in the theory of synchronous machines. The last term in equation (**7**) corresponds to a *supplementary reactance*

$$x_s = 0.5\,\omega\,\Delta\,L \qquad (9)$$

The corresponding voltage drop, $x_s\,I\,\mathrm{Sin}\,(\alpha + \psi)$, *leads* the main reactance drop $I\,x$ by the angle $2\,\psi$, because

$$(\alpha + \psi) = (\alpha - \psi) + 2\,\psi \qquad (10)$$

Thus, the following expression is reached for the vector of total reactive voltage drop in the armature:

$$\text{Reactive drop} = I\,x\,\underline{/90°} + I\,x_s\,\underline{/90° + 2\,\psi} \qquad (11)$$

The quantities x and x_s are expressed by equations (**8**) and (**9**); the values of L and $\Delta\,L$ are shown in Fig. 1. The angle notation in equation (**11**) means that $I\,x$ leads the vector I by 90 deg. and $I\,x_s$ leads I by 90 deg. $+\,2\,\psi$. In other words, $I\,x_s$ leads $I\,x$ by $2\,\psi$.

II. A Modified Blondel Diagram

An application of these results to the Blondel diagram is shown in Figs. 2 and 3 which are generalized Figs. 40 and 41 in the "Magnetic Circuit." Fig. 2 represents a generator at a lagging current and Fig. 3 a motor at a leading current[6]. The current I is shown in both cases from the point of view of the machine itself (and not of the line) so that the phase angle ϕ, when the machine is operating as a motor, is greater than 90 deg. This method of representation is of advantage in that the same diagram and the same set of formulas cover operation both as a generator and as a motor.

Beginning with the line voltage E, Fig. 2, the ohmic drop $A\,B = I\,r$ is added in phase with the current, and the average reactive drop $B\,D = I\,x$ in leading quadrature with it. The supplementary reactive drop, $I\,x_s = D\,D'$, is added at an angle $2\,\psi$ to $B\,D$, in the positive (counter-clockwise) direction. In the case of the motor, ψ is greater than 90 deg., and $2\,\psi$ is greater than 180 deg. $E_0 = O\,D'$ is the total induced electromotive force. The direction $O\,C$ is that of the induced electromotive force at no load, or the center line of the pole. Hence, by constructing a right-angle triangle $D'\,G\,O$, with $O\,D'$ as hypotenuse, the net voltage $O\,G = E_n$ induced by the real poles is obtained, and the voltage $G\,D' = E_t$ induced by the fictitious (transverse) poles.

From equations (**83**) to (**85**) on p. 156 of the "*Magnetic Circuit,*" it will be seen that instead of drawing E_t normal to $O\,C$, a vector $D'\,C = E_t'$ can be drawn parallel to $I\,x$. This procedure is necessary when the angle ψ is not known, and in fact can be used to determine this angle, namely, by completing the parallelogram $D\,D'\,C\,H$ and extending $D\,H$ to its intersection with $O\,C$ at K[7]. In the triangle $K\,H\,C$ the angle at H is equal to $2\,\psi$ by construction; the angle at K is equal to 90 deg. $-\,\psi$, because $O\,Q\,K$ is a right triangle, and the angle at 0 is equal to ψ. Thus, in the triangle $K\,H\,C$ the remaining angle, at C, is also equal to 90 deg. $-\,\psi$.

6. The current and voltage notation has been changed from i and e to I and E; the induced voltage is denoted by E_0 in place of E. I has been defined above as the amplitude of the current. There is no objection, however, to considering I and E in the diagram as vectors of the effective values.

7. The point K is of considerable importance in diagrams of synchronous machines, and Blondel uses the term Joubertian e. m. f. for the value of $O\,K$. It is convenient to call K the Joubertian point.

The triangle is isosceles and consequently $H K = i x_s$. This gives the following construction for the angles ψ and θ:

Lay off $O A$ and $A B$, and draw the direction $B K$, normal to the current. Lay off $B K = I x + E_t' + I x_s$, and connect point K to 0. This will give both the internal phase angle ψ and the displacement of torque angle θ. The latter is the electrical angle by which the pole structure of the loaded machine is advanced (or retarded) with respect to an identical unloaded machine connected to the same bus bars.

If it is required to compute the required excitation, complete the diagram by laying off $B\ D'' = I$

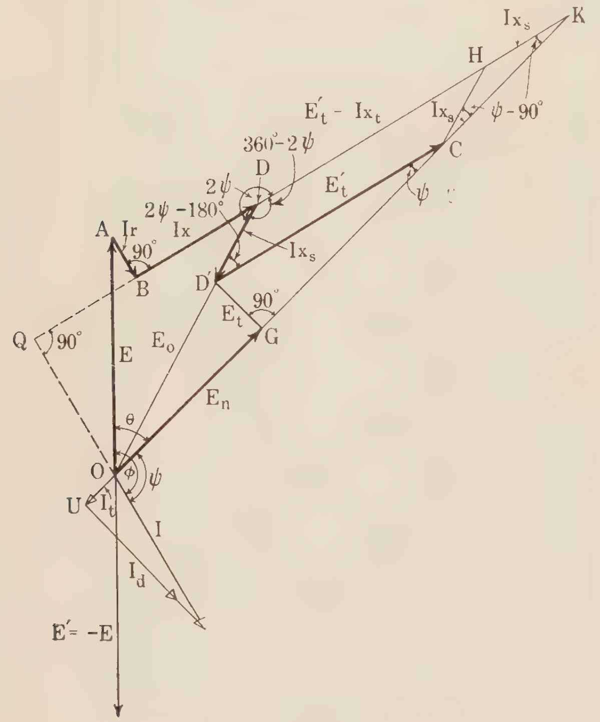

FIG. 3—A MODIFIED BLONDEL DIAGRAM, SIMILAR TO FIG. 2, FOR SYNCHRONOUS MOTOR

$(x - x_s)$, and through D'' draw the straight line $N N'$ normal to $O K$. This will determine the net induced electromotive force $O G = E_n$; from the no-load saturation curve, the corresponding net excitation, M_n, can be found. To this excitation, the direct armature reaction, M_d, is added [or subtracted, if sin ψ is negative, *ibid.*, equation (**79**)]. This will give the required field excitation, M_f, at that particular load.

Most of the construction lines and angles indicated in Fig. 2 are also shown in Fig. 3, and the description given above, with slight modifications, may also be followed in Fig. 3.

III. ANALYTICAL SOLUTION

The heavily drawn polygon in Fig. 2 can be represented in the cissoidal complex form by the equation

$$E \text{ Cis } \phi + I r \text{ Cis } 0 + I x \text{ Cis } 90 \text{ deg.} + I x_s \text{ Cis } (90 \text{ deg.} + 2\psi) + I x_t \text{ Cis } 90 \text{ deg.} = (E_n + I x_t \text{ Sin } \psi) \text{ Cis } \psi \quad (\mathbf{12})$$

where

$$\text{Cis } \phi = \text{Cos } \phi + j \text{ Sin } \phi = \epsilon^{j\phi} \quad (\mathbf{12a})$$

and also

$$I x_t = E_t' = I k_t k_b m n v \quad (\mathbf{13})$$

[*Magnetic Circuit*, p. 156, equation (**84**)], so that the *transverse reactance*, corresponding to the transverse armature reaction, is

$$x_t = k_t k_b m n v \quad (\mathbf{13a})$$

Equation (**12**) expresses the fact that the geometric sum of $O A$, $A B$, $B D$, $D D'$ and $D' C$ is equal to $O G + G C$. To solve this equation for ψ, multiply both sides by Cis (90 deg. $- \psi$)[8]. The real part of the resultant expression is

$$E \text{ Sin } (\psi - \phi) + I r \text{ Sin } \psi - I x \text{ Cos } \psi - I x_s \text{ Cos } \psi - I x_t \text{ Cos } \psi = 0 \quad (\mathbf{14})$$

Dividing throughout by Cos ψ and solving for tan ψ,

$$\tan \psi = (E \text{ Sin } \phi + x_0 I)/(E \text{ Cos } \phi + I r) \quad (\mathbf{15})$$

where x_0 is the total equivalent reactance:

$$x_0 = x + x_t + x_s \quad (\mathbf{15a})$$

A reference to Fig. 2 will show that equation (**15**) could be written directly from the triangle $O Q K$, since in this triangle

$$\tan \psi = Q K / O Q \quad (\mathbf{16})$$

However, a derivation from equation (**12**) has been deemed to be of sufficient interest to be included in this paper for the sake of illustrating the general method of solution of such problems. This method is entirely automatic, while the particular geometric relations in a given problem may or may not be evident. The displacement angle θ is determined from the relationship

$$\theta = \psi - \phi \quad (\mathbf{16a})$$

for a motor θ is negative.

Equating separately the real and the imaginary parts on the two sides of equation (**12**), and solving each for the term with E_n, we obtain:

$$E_n \text{ Cos } \psi = E \text{ Cos } \phi + I r - I (x_s + 0.5 x_t) \text{ Sin } 2\psi \quad (\mathbf{17})$$

$$E_n \text{ Sin } \psi = E \text{ Sin } \phi + I (x + 0.5 x_t) + I (x_s + 0.5 x_t) \text{ Cos } 2\psi \quad (\mathbf{18})$$

Knowing the angle ψ from equation (**15**), E_n can be computed from either equation (**17**) or (**18**). When ψ is near zero, it is preferable to use equation (**17**); when ψ is nearly 90 deg., equation (**18**) will give more accurate results.

A graphical interpretation of equations (**17**) and (**18**) is shown in Fig. 4. This diagram is identical with Fig. 2, except that a line, $G W$, is drawn perpendicular to $O Q$. The lengths $D' R$ and $R G$ are each equal to $0.5 E_t'$. Equation (**17**) then simply means that

$$O W = O Q - W Q \quad (\mathbf{19})$$

while equation (**18**) states that

$$W G = R G + W R \quad (\mathbf{20})$$

8. Two Cis operators are multiplied by simply adding the angles; that is, Cis a. Cis b = Cis $(a + b)$. This follows directly from the exponential expression in equation (**12a**); see also V. Karapetoff, *The Electric Circuit*, p. 93, equation (**154**).

Whether or not this graphical relationship will prove to be of further practical interest, remains to be seen. It has been deemed advisable to note it here, as a check on the formulas.

The theory deduced above has been checked on a machine with an exceptionally high leakage reactance. The assumption of a constant leakage reactance, deduced from the short-circuit test and from the design data of the machine, led to a wide discrepancy between the observed and computed performance characteristics.

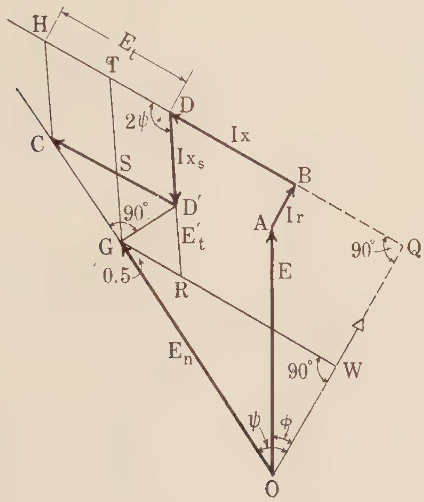

Fig. 4—A Graphical Interpretation of Equations (17) and (18)

istics. On the other hand, by assuming reasonable values of the average and supplementary leakage reactances, the current and voltage relations, as well as the torque angle θ, were found to agree quite closely with the test data[9].

In conclusion, the author wishes to express his appreciation to Mr. R. E. Doherty, Consulting Engineer of the General Electric Company, for suggesting this investigation and for encouragement while it was in progress.

CORRESPONDENCE

DISCUSSION ON ALTERNATING-CURRENT ANALYSIS ALTERNATING-CURRENT ANALYSIS (MERSHON)

To the Editor:

The statement which appeared in the May 1926 Journal concerning the use in several text-books of the method presented by Mr. Mershon was hastily written on the basis of impression rather than fact. Since then I have attempted, but failed, to find the method in any of the usual texts. I take this opportunity to correct my error and apologize to Mr. Mershon.

Hubert H. Race

9. For a different treatment of the subject see R. Bruderlin, *Drehfeldmaschinen mit veränderlicher Reaktanz, Arch. f. Elekt.*, 1924, Vol. 13, p. 12.

PREDETERMINATION OF SELF COOLED, OIL IMMERSED TRANSFORMER TEMPERATURES BEFORE CONDITIONS ARE CONSTANT

The predetermination of temperature rise-time-curves for transformers is of the utmost importance for the calculation of permissible durations of overloading.

In the paper of *Mr. Cooney* in the Journal of December 1925 methods are given to obtain a more accurate calculation of these curves. The special methods pointed out by the author are, first, the separation of the temperature rise of the winding above the ambiant air in the temperature rise of the winding above the oil and the temperature rise of the oil above the ambient air and, second, in taking into account the fact that the heat dissipation increases more rapidly than according to the first power of the temperature difference.

My note refers to this last point. The fact that the coefficient of cooling of a transformer increases with increase of temperature difference is expressed by the author in the formula:

$$\theta = k\, P^{0,8} \qquad \textbf{(a)}$$

This formula is used to calculate the final temperature rise at different losses (loads).

For the tracing of the temperature rise-time-curve the general known ϵ relation is used.

It seems to me that a temperature rise-time-curve still more in accordance with test curves may be obtained by taking into account the formula (**a**) also for the calculation of this curve. We shall give below a method by which this can be done.

The formula (**a**)

$$\theta = k\, P^{0,8}$$

can be written

$$\theta = \left(\frac{k^{1,25}}{\theta^{0,25}} \right) P \qquad \textbf{(b)}$$

By this formula it can be seen that the coefficient between brackets diminishes by increased values of θ. According to formula (*b*) the coefficient of dissipation will vary with the value $\theta^{0,25}$.

Thus, the value for the loss dissipated can be written:

$$K_f \frac{\theta^{0,25}}{\theta_f^{0,25}}\, \theta \qquad \textbf{(c)}$$

In this formula $K_f \cdot \theta_f$ is the loss dissipated at the temperature difference θ_f, for the generated loss can be written

$$W = W_0\,(1 + \beta\,\theta)$$

W_0 is the loss for $\theta = 0$.

β is indifferent from α and takes into account the fact that the loss consists of iron and copper losses. Taking $\alpha = 0.004$ and the ratio between the iron and copper losses to be 1 : 3 the coefficient β will be 0.003.

The formula (3) of the paper can be written now as follows:

$$W_0\,(1+\beta\,\theta) = C\,\frac{d\,\theta}{d\,t} + K_f\,\frac{\theta^{0.25}}{\theta_f^{\,0.25}}\,.\,\theta$$

Taking the time constant:

$$T_\epsilon = \frac{C\,\theta_f}{W_0}$$

the following equation is obtained

$$\frac{d\,t}{d\,\theta} = T_\epsilon\,\frac{\theta_f^{0.25}}{\theta_f^{1.25} - \theta^{1.25} + \beta\,\theta\,\theta_f\,(\theta_f^{0.25} - \theta^{0.25})} \quad (\mathbf{d})$$

The integration of this formula is difficult. The curve can be easily computed, however, by taking small

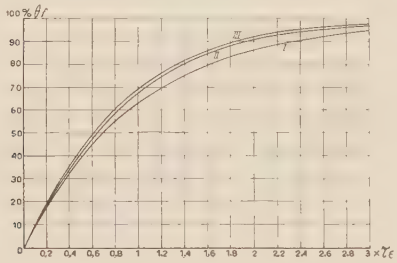

Fig. 1

intervals $\Delta\,\theta$ and calculating for the mean value of θ of this interval the value of $\frac{\Delta\,t}{\Delta\,\theta}$. The time intervals can be obtained then by multiplying $\frac{\Delta\,t}{\Delta\,\theta}$ by $\Delta\ \theta$.

In this way the curve III of Fig. 1 is obtained. For θ_f is taken 100, for $T_\epsilon = 1$ and for $\beta = 0.003$.

Curve II is obtained by taking $\beta = 0.$, *i.e.*, by assuming the losses to be constant at all temperatures.

Curve I shows the well known ϵ curve.

In the middle part of the curves, III and II show a stronger curvature (radius of curvature smaller) than the curve I.

The fact that test values show generally the same deviation from the simple ϵ curve proves that the curve III is the more correct one.

Appendix

Derivation of formula (**d**).

$$W_0\,(1+\beta\,\theta) = C\,\frac{d\,\theta}{d\,t} + K_f\,\frac{\theta^{0.25}}{\theta_f^{0.25}}\,\theta$$

For $\theta = \theta_f$

$$W_0\,(1+\beta\,\theta_f) = K_f\,\theta_f \text{ or } K_f = \frac{W_0\,(1+\beta\,\theta_f)}{\theta_f}$$

Thus

$W_0(1+\beta\,\theta) = C\ \ d\,\theta - + W_0\,1 + \beta\,\theta_f$

$$W_0(1+\beta\,\theta) = C\,\frac{d\,\theta}{d\,t} + W_0\,\frac{1+\beta\,\theta_f}{\theta_f}\;\frac{\theta^{0.25}}{\theta_f^{0.25}}\,\theta$$

$$W_0\left[1 + \beta\,\theta - \frac{\theta^{1.25}}{\theta_f^{1.25}} - \beta\,\frac{\theta^{1.25}}{\theta_f^{0.25}}\right] = C\,\frac{d\,\theta}{d\,t}$$

$$W_0\left[1 - \frac{\theta^{1.25}}{\theta_f^{1.25}} + \beta\,\theta\left(1 - \frac{\theta^{0.25}}{\theta_f^{0.25}}\right)\right] = C\,\frac{d\,\theta}{d\,t}$$

$$\frac{d\,t}{d\,\theta} = \frac{C\,.\,\theta_f}{W_0}\;\frac{\theta^{0.25}}{\theta_f^{1.25} - \theta^{1.25} + \beta\,\theta\,\theta_f\,(\theta_f^{0.25} - \theta^{0.25})}$$

$$= T_\epsilon\,\frac{\theta^{0.25}}{\theta_f^{1.25} - \theta^{1.25} + \beta\,\theta\,\theta_f\,(\theta_f^{0.25} - \theta^{0.25})}$$

Thomas Rosskopf—Member I. E. C.,
Nijmegen, Holland

POSSIBLE DISCONTINUANCE OF RADIO STANDARD FREQUENCY TRANSMISSIONS

BY BUREAU OF STANDARDS

Since March, 1923, the Bureau of Standards has been transmitting, twice a month, radio signals of definitely announced frequencies for use by the public in standardizing frequency meters (wave meters) and transmitting and receiving apparatus. The signals are transmitted from the Bureau station, W W V, Washington, D. C., and from station 6XBM, Stanford University, California.

Since other means of freely disseminating the Bureau's standards of frequency are becoming increasingly available, the Bureau has considered the termination of the standard-frequency transmissions. The other means referred to are the lists of standard-frequency stations regularly given in the Radio Service Bulletin, published by the Bureau of Navigation, the use of piezo oscillators, and the wide availability of reliable standards and test service from a number of laboratories that do commercial testing of frequency meters. None of these means were available when the standard-frequency transmissions were inaugurated.

The standard-frequency transmission schedules already announced to extend through June and perhaps to October will be carried out as published, but the Bureau of Standards is announcing the possible termination of the service after that date in order that persons who depend upon the service in any special way may inform the Bureau of any objection to its termination, especially persons in the western part of the United States, who have been utilizing the signals from Stanford University, until the listing of standard-frequency stations on the west coast should have been begun. Letters on this subject may be addressed to Bureau of Standards, Department of Commerce, Washington, D. C.

Discussion at Midwinter Convention

SUPERVISORY SYSTEMS FOR ELECTRIC POWER APPARATUS[1]

(LICHTENBERG)

NEW YORK, N. Y., FEBRUARY, 9, 1926

C. E. Stewart: I should like, briefly, to call attention to one or two things of interest. In the first place, supervisory systems have passed the experimental stage. We have had actual service out of the systems so that we know that they are successful in the field for which they are intended. By the end of this year, systems put out by the General Electric Company alone will have supervision over some 2500 oil circuit breakers or their equivalent. We shall have in service a distributor type whereby a dispatcher at a central point will have supervision over breakers located in twenty-two out-lying stations.

Another very interesting application of supervisory systems will be made on an electrified railroad division sixty miles long between Chicago and South Bend, whereby a load dispatcher in Chicago will control eight automatic stations by means of a carrier selector system operating over one wire and ground-rail return. He will be able to start and stop any station, open and close the feeders going out from the station, and also control incoming lines in some cases.

R. J. Wensley: Mr. Lichtenberg says that telephone relays are not suited for supervisory control service. With this statement I do not agree. I would like to call attention to several installations in the New York area which depend entirely on telephone relays for reliability in operation. The equipments in actual operation seem to be the best refutation of Mr. Lichtenberg's condemnation of telephone relays.

The Long Island Railroad has one of the simple audible types in service controlling a remote 600-volt switch house. It is controlled by a dial and a howler gives an audible answer. It works over two wires and is the least expensive type of control.

This same company has a more elaborate equipment of the code-visual type in service at Amityville controlling one 2000-kw. converter in 600-volt railway service.

The New York Edison Company has a remote selective metering equipment in service at their Forty-First Street substation which transmits readings of volts and amperes over standard telephone cable.

The New York and Queens Electric Light and Power Company has a very comprehensive set of relay-visual equipment in the Woodhaven substation. With it they can control oil breakers, adjust induction regulators, bring in spare regulator and transformer when needed, and make necessary simultaneous readings of a-c. volts and amperes. These functions are all accomplished over telephone cable with a relatively few wires.

The most extensive equipment in this area is that on Staten Island. The equipment is used jointly by the Staten Island Rapid Transit Company and the Staten Island Edison Company. It is of the all-relay visual type. Five railway substations and one power-distribution substation are controlled from one dispatching point. Two separate-control desks use the same relay equipment to handle the business of the two operating companies.

H. C. Don Carlos (communicated after adjournment): In the operation of two generating stations under supervisory control, the Hydro-Electric Power Commission has encountered, among others, some very interesting protective problems. Although the final step in remedying certain troubles has not yet been taken, the following comments on them may be of interest to the profession.

The stations in question are near Campbellford, Ontario, on the Trent river, a navigable stream on which they form three successive developments with navigable reaches intervening. Ranney Falls or No. 10, the upstream station, is the point of control for Nos. 9 and 8, the total distance between plants 10 and 8 being three and a half miles. In No. 9 there are three vertical generators, each of 1400-kv-a. capacity, and in No. 8, three vertical generators of 2000-kv-a. capacity each. In common with a number of other stations, they supply power to a 44,000-volt, 60-cycle network, complicated by a large number of loops.

Since the navigation regulations limit the permissible variation of the level of the small reaches between the plants to about two inches, there is practically no storage available, and consequently very exact information is required at the control point on reach levels, plant output, gate openings (in tenths) of all turbines, as well as switch positions and various other control data. For each of the stations, something over fifty supervisory operations are performed in addition to the transmission of three graphic records. A twenty-pair standard, lead-covered telephone cable, located on a separate pole line, 25 ft. from a 44,000-volt power line, connects No. 10 to No. 9, and a ten-pair cable continues on to No. 8.

The No. 8 generating station went into operation under manual control, using automatic equipment, September 11, 1924, and under remote supervisory control, January 13, 1925. A great deal of trouble was at first experienced, which required patient study and careful analysis to eliminate. With few exceptions the equipment itself is now performing very well and gives promise of ultimate success if the disturbing effects of power short-circuits and lightning trouble can be overcome.

Soon after the supervisory cable went into operation, trouble began to develop in it, affecting one or more conductors each time, and occasionally actual burn-outs occurred. The more serious faults were traced down and eliminated, but after a time all spare conductors had been used, and finally we were left without sufficient clear wires to operate.

Induced disturbances due, to the proximity of the 44,000-volt power line, were at first suspected as the cause of our trouble, but theoretical considerations showed that since the sheath was grounded at all three stations, inductive effects could not be responsible. The use of insulating joints in the cable sheath, splitting it into numerous sections grounded at each end, was one of the proposals most frequently advanced by those who were not thoroughly familiar with the problem.

For various reasons, the sheath must be grounded to the apparatus ground of all three stations. The main trouble is caused by differences in potential between the so-called grounds (*i. e.*, the prevailing potential of the ground leads and steel work within the building) of any two of the three stations due to our inability to obtain a sufficiently high-capacity and low-resistance "ground."

This potential difference is uniformly distributed over the cable sheath (which carried a portion of the fault current) between the two stations. The conductors, however, are normally at uniform potential from end to end, and their insulation is quite unable to withstand the stresses due to the potential drop along the sheath, which may be upwards of 8000 volts.

This surprising figure has a simple explanation. The ground resistance at each of the three stations is in the order of two ohms each, and the cable-sheath resistance is nearly 10 ohms. The possible fault current is in the order of 3000 amperes. Duly considering the return distribution of fault current, calculations and tests indicate a probable maximum potential difference of 8000 volts.

It should be remarked that the frequency of our troubles is attributed to the use at No. 10 of a common ground for the power neutral and the station apparatus (the neutrals at Nos. 9 and 8 are not grounded), so that a 44,000-volt fault anywhere on the system causes a difference in potential between the station

1. A. I. E. E. JOURNAL, February, 1926, p. 116.

ground at No. 10 and those at Nos. 9 and 8. This, of course, occurs despite the fact that the power neutral is grounded at two other locations. To remedy this condition, a separate ground for the power neutral has recently been installed at a considerable distance from the station ground, as a result of which the station ground, in large measure, is freed from variations in potential due to fault currents in the neutral. When again in operation, the supervisory cable will thus be undisturbed by faults other than those at one of the three stations in question.

Among the numerous remedies considered may be mentioned:

a. The adoption of a-c. supervisory operation with transformers at each end of the cable completely isolating the conductors from the station ground, or from any apparatus connected thereto.

b. The use of a stabilizing ground conductor of sufficient admittance to limit the possible voltage difference between the three station grounds to an amount which would not prove injurious to the cable.

c. The use of transformers, the primary of which would be connected between the cable sheath and the station ground, and the secondary of which would consist of all the other conductors of the cable wound in close coupling and of such ratio (approximately 1:1) as to cause the conductors to follow approximately the same potential gradient as the sheath.

In addition to the foregoing, the idea of installing a highly insulated cable has been advanced, but this would not help matters since the supervisory equipment, which, in itself, will not withstand high potentials, would be still subjected to the severe stresses and cannot, according to the manufacturer, be protected against trouble of the nature described without blowing fuses which render it inoperative until an attendant makes replacements.

Of the three schemes mentioned, (a), which was developed independently by the Commission and the manufacturer, appears to have merit, but it is expensive and involves the use of additional equipment in the automatic train, and the consequent additional care and maintenance and risk of failure is objectionable. Plan (b) is also expensive, and lacking in some of the merits of (a), although free from its shortcomings. On the whole, (c), proposed by R. W. Osborne, telephone engineer of the Commission, seems to offer the greatest return for the investment, and the greatest promise of satisfactory ultimate operation. Preliminary tests of its behavior under transient disturbances are now pending.

It is interesting to note the manufacturer's contention that conditions exist in this installation which have not been encountered before, yet we are all agreed that the trouble is due to differences in potential between the ground conductors of any two of the stations. So far as I am aware, our ground resistances are not high for isolated plants and are not capable of any considerable improvement consistent with a reasonable outlay which can be relied upon the year round. In fact, the expensive proposition of ground stabilization by means of an interconnecting cable (scheme b) would be cheaper, and, if feasible, far more positive than an attempt to overcome the trouble by further improving the station grounds.

The question of how usual or unusual the conditions are can be decided by any interested engineer who has a general knowledge of the dependable minimum resistances of ground connections, and if he has any particular case in mind and knows the ohmic resistance of the grounds and the maximum fault current, he can calculate the probable resulting potentials in a supervisory installation from causes such as I have described.

In his remarks under the heading "Protection," Mr. Lichtenberg has shown a very open mind and has stated his interest in the experience of operating companies. Some of his views seem to be at variance with the conclusions drawn in the foregoing, and in support of these conclusions I can only add that practical operating experience as well as theory seem to be in agreement—a circumstance which always carries weight.

F. R. McBerty (communicated after adjournment): Mr. Lichtenberg's contribution on the subject of the maintenance of supervisory systems composed of telephone relays (which is in substance a repetition of his remarks before the meeting reported in the JOURNAL of August, 1925, page 879) demands some qualification in the records of the Institute. Mr. Lichtenberg's experience with such relays must have been both limited and unfortunate. Having participated in the design of the telephone relays most extensively used throughout the world and being now the manufacturer of an "all-relay" supervisory system for power equipments, I can perhaps offer definite and accurate information on these matters.

Mr. Lichtenberg is in error in his statement as to the fundamental ideas and assumptions present in the minds of the designers of telephone relays. The designers as a matter of fact did not work under the idea that the relays would be or could be inspected frequently or that some person would be present at one end or the other of a line equipped with them to note their failures and ensure their operation. On the contrary they had in mind that such relays would be used in great numbers, would be operated by persons intent on telephonic communication, would be operated in constantly shifting combinations which would make discovery of individual failure difficult, and would largely determine the reliability of telephone service. The designing and making of relays which should be both sufficiently cheap in cost and sufficiently reliable in service was so well done that there are now scores of millions of them in service throughout the world, of which a large part have been in operation for a quarter century performing thousands of millions of operations per day with a percentage of failure so slight that of all common causes of defect in the operation of telephone systems, the failures of telephone relays form a negligible factor.

Among manual-exchange systems composed of such relays there is no daily inspection, and in most cases not even an annual nor a decennial inspection or test; in machine-switching systems the faults due to relays are a trifling factor in comparison with the faults caused by step-by-step or power-driven moving switch mechanism.

The supervisory system illustrated in Fig. 12 of Mr. Lichtenberg's paper is composed of telephone relays of a type used for performing selection in the automanual city telephone exchange systems and in automatic or dial-controlled private exchanges. As an example, a single unit has performed on test more than fifty million circuit closings without failure or significant change in contact resistance. There are large city exchanges in operation in which the initial selections for all originating telephone calls are made by such relays comprising a total of about sixty thousand relays, some of which have been in continual operation for fifteen years, which are never inspected or tested and which collectively show failures or defects in operation numbering no more than two hundred cases per year in the performance of about five hundred million selective operations. In a particular large exchange the ratio of failures to selections is about one in five million. These relays have never been given routine tests and have had only occasional and in some cases, no inspection since installation.

Reference was made by Mr. Lichtenberg, in his paper dealing with the same subject matter reported in the JOURNAL of last August, to the wide range of temperature under which supervisory systems must operate. Relay selection gear fulfills these requirements far better than any other form of selecting mechanism in existence. As an example, there is an unattended remote-controlled all-relay telephone exchange in Ohio, which gives continual local and long-distance service to about 140 subscribers, situated at a distance of sixteen miles from a city and operated over a pair of control wires from the city, housed in a small building without any means of controlling temperature or hu-

midity. The relay selection equipment has developed only one fault in fourteen months, has had only casual inspection without any adjustment or repair whatever in seven months, and has been without even a visit from an inspector for ten weeks during the winter. During this time there have been no cases of interruption of service or of failures in selection traceable to the relay switching equipment.

The conspicuous merits of the relay selection systems composed of telephone relays, as compared with step-by-step, ratchet-driven and with rotary power-driven selective gear, are as follows:

The moving parts of the relays are pivoted armatures and long flexing flat springs only, with small and fixed ranges of movement with ample factor of safety in power working against relatively unchanging frictional resistance. The contacts themselves, when multiplied, are for all practical purposes free from failure. When properly constructed the relays never afterwards require adjustment or cleaning. The complications of the selective gear lie in the circuits, which being in the form of soldered and cabled wire net works are unchanging and permanent.

Such relays could readily be made much heavier and even more ornamental, but so far as I am aware there are no reasons other than personal taste to warrant the added expense. After all the function of a relay is to move a bit of bronze or platinum against another bit, and telephone relays do that very well.

On the contrary step-by-step or constantly moving selective mechanism is in all cases dependent upon the operation of relays, subject to whatever failures may characterize relays, with the additional handicap of being itself composed of numerous small moving parts—ratchets, pawls, retractile springs and brushes—among which accurate, minute, mechanical adjustments must be closely maintained under driving forces varying widely and against frictional resistance and inertia also varying widely. Its complications lie largely in nice relations of moving parts and forces. In order to be operative such mechanism universally requires rather closely regulated voltage, must be adjusted, lubricated, and kept free from dust and oxidized metal—conditions which change with use, atmospheric conditions and time.

Chester Lichtenberg: Supervisory systems, as mentioned in the paper, are new. Only a few of them have been in service sufficiently long to obtain experience with them. The discussion presented by Mr. Don Carlos is, therefore, exceedingly valuable since it presents in most thorough fashion an operating problem together with three suggested solutions of it.

The discussions of Messrs. Stewart, Wensley and McBerty present data which supplement that given in the paper and express opinions relative to operation. These opinions are indeed very valuable, since designers of supervisory systems will no doubt examine and take from them such suggestions as will prove of material benefit to the art.

A discussion of supervisory systems cannot be concluded without again making clear the fact that these systems are quite different from remote-control systems and, therefore, their application must be carefully made if they are to be successful.

THE CROSS-FIELD THEORY OF ALTERNATING-CURRENT MACHINES[1]

(WEST)

NEW YORK, N. Y., FEBRUARY 11, 1926

P. L. Alger: Mr. West has presented in his paper a business-like and accurate way of obtaining the characteristics of an a-c. motor. The method is particularly adapted, and, in fact, was especially intended, for use by engineers having to do with large numbers of motors. Probably we all agree that the circle diagram, or some similar graphical method, is most suitable for college instruction, and for use by persons only dealing with motors occasionally. When large quantities of motors are to be designed, however, it is necessary to take into account many of the minor features of the theory, and, at the same time, to make the method extremely systematic. Thus, I am heartily in sympathy with the point of view which Mr. West expounds so thoroughly.

While the title of the paper emphasizes the cross-field theory, the same method could be used equally well with the rotating-field theory, for most machines. It is my opinion that both the rotating-field and the cross-field theories have advantages in particular cases, and that a complete understanding of design can be obtained only by a mastery of both theories. So far as I know, there is only one respect in which the two theories give different results.

This one exception occurs when the secondary winding of a single-phase machine has sufficient skin effect to make its effective resistance and reactance at line frequency appreciably different from their values with direct current. Since the actual current in any one secondary conductor consists of components of two different frequencies, the two components encounter different impedances, and so the effective voltage across the conductor is not equal to the product of the total current by any definite value of impedance. The cross-field theory treats the entire current in one axis as being of line frequency, and so does not take into account the variation of impedance with frequency. On this account, the rotating-field theory gives more accurate results for machines of this type.

I believe that the obvious objection to Mr. West's method, that it is very complicated, can be largely overcome by a study of the formulas, and their rearrangement into a form consisting of a principal term and various corrective terms. For example, if the magnetizing reactance is large by comparison with the leakage reactance, many of the formulas can be simplified by expressing them in power series in terms of $\dfrac{x}{X_m}$, and then neglecting higher powers than the first of this ratio. In some cases, the most complicated formulas can be put into a simple and usable form by assuming average values for certain of the less important constants, and preparing charts showing the effects of variations in the major constants. Then, correction formulas can be made up, showing the effects upon the result of changes in the minor variables made independently, and these auxiliary formulas can be used whenever especial accuracy is desired.

I believe that the ultimate design method is one which takes into account all of the variables, but only carries the result to the desired accuracy, and no further.

K. L. Hansen: In his analysis of the single-phase, induction motor, Mr. West has followed the usual and much discussed method of the cross-field theory. He has, apparently, introduced a slight modification by adding the secondary leakage flux to the mutual flux in the expressions for some of the induced voltages. The introduction of this refinement is, however, incidental and is obviously not the main object of the paper.

In the opening paragraph the author states that some phenomena are more easily understood by a study following the revolving-field theory, and other phenomena are made more clear by use of the cross-field theory. This statement, in connection with the title of the paper, would naturally lead one to believe that some distinct advantage of the cross-field theory over the revolving-field theory would be pointed out, at least in the specific instances which the author has chosen for illustration. The paper does not fulfill this expectation.

According to the author, the choice of methods should depend on what is most desired, *e. g.*, speed, accuracy, or aid to visualization. From the standpoint of speed and accuracy the cross-field theory obviously offers no advantage over the rotating-field theory. From the standpoint of visualization or physical conception the cross-field theory appears to be rather inferior to the rotating-field theory. Indeed, at the very outset an artifice

1. A. I. E. E. JOURNAL, February, 1926, p. 160.

is resorted to of considering the squirrel cage as the equivalent to a commutated winding with brushes bearing on the commutator short-circuited on themselves in the transformer and field axes.

There can be no objection to replacing the actual circuits we are dealing with by artificial equivalent ones when something is gained from the standpoint of clearness or shortening of the analytical work; but in this instance nothing is apparently gained thereby. In the revolving-field theory the squirrel cage is considered to be exactly what it is—a system of polyphase circuits. It seems that the currents flowing in the artificial secondary circuits employed by the author are of constant frequency and that therefore the secondary reactance x_2 is a constant quantity independent of the slip. Have the calculations in the paper been made on that assumption, and if so, do they lead to correct results?

A few years ago a writer in the JOURNAL argued that when several theories are advanced to explain the same phenomena, economy of thought demands that all but one of these theories be abandoned, unless each of the several theories possesses distinct advantages not possessed by the others. He then proceeded to make a misapplication of the revolving-field theory, and as his deductions naturally were in error he concluded that the revolving field theory is more liable than the cross-field theory to lead to erroneous results. He also was laboring under the delusion that the revolving-field theory is not applicable to commutator motors, and therefore advocated that this theory be abandoned in favor of the cross-field theory.

The present writer's opinion is that the point of retaining, in the interest of economy of thought, only one theory to explain a certain set of phenomena, is well taken; but I can not agree that in this case the revolving-field theory should be abandoned. My preference for the revolving-field theory is that is appears to be the more general one of the two. If the two components of the revolving field are equal, we have a single-phase system; if they are unequal, we have an unbalanced polyphase system. If one component vanishes, we have a balanced polyphase system, and if the angular velocity of the rotating field is equal to zero, we have a direct-current system. In other words, all phenomena of rotating electrical machines can be explained as special cases of the general theory based on two oppositely rotating magnetic fields.

H. R. West: I agree with Mr. Alger that the best method of calculation is that which gives results of the necessary accuracy, and no more, with the least amount of labor. On the other hand, I cannot accept the statement that the methods of calculation that I have given are very complicated. The greater part of the work of calculating a motor is contained in the tabulated part. Examination of this tabulated part of the calculation will show that nearly all of the rows of numbers are obtained with only one setting of the slide rule, or merely by addition. With a very little practise, one will find that the calculation can be carried through very easily and quickly. The method given for the single-phase induction motor has been compared in actual trial with the most up-to-date methods of accurately calculating the polyphase induction-motor characteristics, and although it has been found to be somewhat more laborious, as obviously it must, since the operation of the single-phase, induction motor is very complicated in comparison to that of the polyphase motor—still it is found to be comparable in the amount of work and time required. Furthermore, anyone who can use a slide rule can carry out the calculation completely. It is not necessary for him to know anything about motors or electric circuits in order to carry out a complete calculation.

There are some very obvious approximations that can be made in the calculations, particularly in calculating the constants F_n and G_n. These approximations would result in very little more than an apparent reduction in the labor of calculating, and therefore the expressions were given in full for the sake of completeness.

As Mr. Alger suggests, a systematically arranged calculation form would probably be found equally helpful in calculating the characteristics of a motor from equations that might be derived by the revolving-field method. However, I do not believe that the revolving-field method of analysis will lead as directly to equations or formulas that are most useful for calculation purposes.

Mr. Hansen calls attention to the terms in my equations that represent the speed voltages corresponding to the rotor leakage fluxes. The inclusion of these terms is not new[2] with the author, although they have been neglected by some writers, generally with only very slight effect on the accuracy of the results.

The correctness of the results that have been obtained by the cross-field method of analysis has been questioned by Mr. Hansen. The exact equivalence of the results obtained by the revolving-field and cross-field methods was demonstrated several years ago[3]. Furthermore, examination of the analytical expression which Mr. Hansen derived for the line current taken by the single-phase induction motor in his very instructive paper[4] on the rotating-field theory will show that his equation is exactly equivalent to the corresponding one of my paper.

Reply to the remaining portions of Mr. Hansen's discussion must consist largely of repetition of the ideas expressed in the opening paragraphs of my paper. Both methods have their own advantages, depending partly on the types of motors. For instance, it is obvious that the revolving-field method should be used for the balanced polyphase induction motor, and the cross-field method should be used for the a-c. series motor. At the same time, I believe that a study of both of these motors from both points of view will often be found worth while. In the case of the single-phase induction motor, which seems to offer the most debatable ground in regard to the cross-field and revolving-field methods, it seems that the revolving-field method is much superior for the purpose of giving a mental picture of how the motor works. At the same time, I have found that the cross-field theory adds to and clarifies that picture. On the other hand, I am convinced that the cross-field method of analysis is more useful for exact analysis, since it leads directly to results that are immediately useful for exact numerical calculation without the necessity of making two separate calculations for a polyphase motor and then combining them.

As Mr. Alger has pointed out, there seems to be only one case in which the revolving-field method can be used and where the cross-field method cannot be used, *i. e.*, where the rotor inductances depend upon the frequencies. Otherwise, one method seems to be as general as the other.

The paper was not intended as an attempt to prove the general superiority of one method over another for any particular motor, but to demonstrate the possibility of using the cross-field method of analysis to obtain readily usable, accurate, numerical methods of calculation of motor characteristics. My experience leads me to believe that such methods of calculation can be most readily derived by the use of the cross-field method, in the case of many kinds of motors, particularly single-phase motors.

DEVELOPMENT AND APPLICATION OF LOADING FOR TELEPHONE CIRCUITS[5]

(SHAW AND FONDILLER)

NEW YORK, N. Y., FEBRUARY 9, 1926

Bancroft Gherardi: The invention of loading and the development of telephone repeaters have, together, revolution-

2. See, for instance, Arnold, Wechselstromtechnik. V 1.
3. Arnold, Wechselstromtechnik, and Karapetoff, JOURNAL A. I. E. E., Aug. 1921.
4. JOURNAL A. I. E. E., February, 1925.
5. A. I. E. E. JOURNAL, March, 1926, p. 253.

ized the engineering of toll-line plants in the United States. For the invention of loading we are indebted to Dr. Pupin.

Before loading was invented, cable was to toll-telephone transmission much the same as strychnine is to the human system. Any great amount of cable produced definitely unfavorable reactions. The advent and application of loading produced a substantial change in this situation. Whereas, before loading was available, a toll-line cable of even twenty or thirty miles in length presented a serious problem which could only be solved by the generous use of copper, loading very much extended the range of cable so that practical toll cables of even 200 mi. length were available. With the advent of telephone repeaters and their use in combination with loading, toll cables 1000 mi. in length or even longer became practical and economical.

Today we are giving commercial telephone service regularly through cable between Boston and New York on the one hand and Chicago on the other. Before the end of 1926 New York and Boston will be connected by an all-cable route to St. Louis. From Boston to St. Louis it will be about 1400 mi. following the route of the cable.

Many other important cable routes are completed or now under way so that within a few years the principal toll routes in the northeastern section of the United States will be cable.

There are several advantages in this type of construction. On the more congested routes right-of-way problems would have been formidable without cable. Between New York and Philadelphia, by the end of this year we would have required twenty 60-wire pole lines to take care in overhead construction of the circuits that we shall have in cable. The maintenance of these lines under unfavorable conditions would have been a formidable problem.

To some, it might appear that the loading coils and repeaters would necessarily be a somewhat incidental factor in the total amount of construction involved in the toll-line cable. This is not the case. Considering a cable between New York and Chicago, it is found that only about 50 per cent of the total cost of the cable is in the cable itself and the structure supporting it.

F. B. Jewett: In looking over the paper and in casting my mind back over the history of my connection with the telephone business (which is in point of time almost coincident with the span of time in which loading has been a factor) I was interested to recall the several steps through which this whole art of loading has gone from the days when it was first presented through Dr. Pupin's work. My mental review included the early stages of our attempts to use loading up to the present time when it is recognized as a factor of very great importance.

I chuckled to myself as I thought of a time, nearly twenty years ago, when we thought our development work as applied to loading was nearing completion. The word went out that we ought to hustle up the work we then had in hand and button up this loading development so that it would be standard for all time and we could take our forces off and go to other things. Well, just as in the case of all things of an engineering nature which have real continuing merit, so it is in the case of loading. Being a real thing, there is no end to the development work and the field of application continues to grow. As the paper states, there are more men engaged in loading development problems today than there ever were in the history of the work; also the problems which open up before us as possible of solution through loading and the combination of loading with repeaters, are more extensive now than they ever have been in the past.

As a result of the work to date, which has resulted not only in improvements in kind but in cheapening the forms of loading, we are continuing to reduce the size and length of circuits on which it is economical to apply loading. At any given stage of the development of a thing like the loading coil, there comes a time when although physically possible of use on certain kinds of circuits, it is economically not feasible to use it because it is cheaper to get the desired result in some other way. But, with the cheapening of loading coils and their improvement, the gage and length of circuits on which loading is commercially applicable and advantageous have been reduced until we are approaching the point where it would appear to be economical to use loading on wires as fine as it is mechanically possible for us to employ them.

As the paper indicates, the development work started by the requirements of loading per se, has ramified in all sorts of unexpected nooks and crannies. It has expanded to include electrochemical processes, matters of tool design for the utilization of those enormously powerful presses for forming the core material, special machinery for winding coils, the kinds of insulating material, a thousand and one things which you wouldn't ordinarily think of as being connected with loading-coil developments. Loading-coil developments have also had profound effect on the methods of line construction. The precision with which we have to space these coils, the accuracy with which we have to maintain the balances between the parts of a circuit and the circuits themselves—all of these things indicate what a vast engineering field has grown up as a result of this thing which appeared relatively so simple.

Just one point in closing: I have no statistics to give but will mention one interesting calculation to indicate what the traffic possibilities are in a group of circuits of modern structure, equipped with loading coils and with modern repeaters. Mention has been made of the New York-Chicago cable. That cable in the main, as far as I know, is a cable of standard size. That means it is a cable which has an outside diameter of 2⅝ in. The lead sheath is ⅛ in. thick and inside there is a core of paper-insulated wires. It is primarily a telephone cable. Just as an illustration, let us consider what the communication-carrying capacity of this telephone cable would be if it were used just as it stands for telegraph purposes instead of telephone. With the voice-frequency multiplex system, it is possible to obtain about ten telegraph channels per telephone pair. If each of these telegraph channels were equipped with multiplex printing telegraph apparatus commonly used by the Western Union Telegraph Company, we could operate about ten thousand printer circuits in each direction. Working simultaneously at their normal speeds, it would be possible with this set-up to transmit between New York and Chicago the whole contents of a New York daily newspaper, exclusive of advertising material, in less than two minutes.

M. I. Pupin: The authors mentioned that it is convenient to discuss the coil-loaded line in terms of its corresponding smooth line. I should like to add one word to that statement —that it is still convenient—because I discussed it that way twenty-six years ago, in my first paper before the American Institute of Electrical Engineers. They also say that "Professor Pupin gave his famous solution in a paper presented before the Institute in May, 1900." That is a very complimentary statement but I should like to see that compliment completed. I should add that in that paper was also given the fundamental mathematical method of treating networks, filters and balancing networks. Before that time no one knew anything about it. They call them filters in West and Bethune Streets. At Columbia University we call them pilot conductors. But they are more persistent than we are, and so they have their own way. But the theory of the filters was first given at Columbia University and not at West Street.

Now, having said all the disagreeable things that I can think of, I am going to add another one which is not so very disagreeable perhaps, or perhaps more so. They talk of the loading coil, the toroidal loading coil. There is a very, very important bit of history attached to that. When I came out with the toroidal form of the loading coil, the engineers of the American Telephone & Telegraph Company couldn't see any virtue in it at all. It took them some time to recognize its virtues but when they did, they recognized them very clearly. Since that time they have been eliminating all other forms of coils that they

employed by the hundreds of thousands in their business.

Now I won't be disagreeable any more. The work that that company has done upon the development of the toroidal coil (invented at Columbia University and not in Bethune St.) is most remarkable. The development went on with a steady progress until today they have a coil that represents scientific research efforts perhaps unequalled by anything else that has happened in the telephone art during the last twenty-five years, since I made the invention.

It is a remarkable result and I think by next year they may have another announcement to make which will be even more remarkable than anything else they have announced so far, but I am not at liberty to talk about that.

It goes without saying that, in the course of the development of an invention, other things are brought in to supplement the invention and it speaks very highly for the loaded telephone cable that it is supplemented so beautifully by the telephone repeater of the vacuum-tube type. A fellow who can't associate with anybody else is not a very good fellow as a rule. An invention that can't stand the companionship of other inventions is probably a poor invention. The loaded-conductor invention takes the repeater invention into its arms and they hug each other and make a beautiful pair of congenial companions. That to me is more encouraging and more complimentary to the loaded-conductor invention than anything else that has happened. Attempts have been made to supplant the loading coil, to get along with repeaters only by adding attenuation equalizers, but they didn't prove practicable. This created the impression in places that the loaded-conductor invention was dead and a friend of mine came to me one day and repeated a sentence which I published in a book some time ago: "Inventions grow old and are superseded by other inventions."

Some one once said to me, "Isn't that a sad expression, Professor? Doesn't that indicate that your invention is dead?"

That doesn't refer to my invention at all. If it did I wouldn't have put it there. It would betray too much disappointment and I dislike exhibitions of disappointment. No, the invention is not dead; it is still alive and quite vigorous.

It is very true, as Mr. Shaw has said, that not even a very small fraction of the hundred million dollars is in my pocket. Anybody can see that; and it isn't in the pockets of the Telephone Company either, which is not quite as obvious. It is in the pockets of the people of the United States, where it belongs, and they will get a great deal more in their pockets in the course of time, because every year the combination of loading and telephone repeaters is saving an enormous amount of money to the people of the United States. And what is it producing? It is producing an effect for which Washington and Lincoln longed. Washington thought of nothing so much as of the consolidation of the American Union. Lincoln, much against his will, even went to war for the purpose of saving that Union and consolidating it.

Now when you hear of that beautiful telephone system, from Boston to New York, to St. Louis and to all the big centers in the United States, tell me of something else that has that power of consolidating the American Union! There is nothing else unless it be the radio broadcasting. That is another electrical art but that is not a part of the paper.

Who has produced this wonderful art which is producing this wonderful effect? I read another passage from my book: "It is not so much the occasional inventor who nurses a great art like telephony and makes it grow beyond all our expectations as it is the intelligence of a well organized and liberally supported research laboratory," like the Bell Telephone Laboratories at West and Bethune Streets, which I have been abusing so much.

The industries of this country have finally discovered the correct method of doing things. Their great research laboratories take the more or less crude ideas of individuals and develop them and put them together as the American Telephone and Telegraph Co. has put together the loaded conductor and the telephone repeater. This is creating one of the finest telephonic systems that the world has ever known, and has gone far beyond our expectations.

The paper testifies to that better than anything I have seen.

William Fondiller and Thomas Shaw: Dr. Jewett has referred to the early stages of loading development work, and recollected that it was thought at that time that loading was to be standardized for all time so that the engineers might give their attention to other problems. While such a consummation may have appeared very desirable to some at that time, new developments in materials and processes and in methods of operation continually open up new fields of investigation and design. Our paper has attempted to chronicle the major steps in this development.

In considering Professor Pupin's discussion, the authors very much regret that he appears to feel that they have not fully recognized his contributions to this art, and that as a result of this has made several remarks which he designates as "disagreeable things."

The paper refers to Professor Pupin's famous solution of the coil-loaded transmission line. It is so generally known that it hardly requires repetition that Professor Pupin obtained the fundamental patents on the coil-loaded line and the toroidal form of loading coil.

As stated at the beginning of the paper, this does not attempt to cover the origin of loading or the early developments of the art, as these have been treated quite fully in earlier papers, particularly Mr. Gherardi's 1911 paper before the Institute. The loading-coil invention, as was true of Bell's original invention and as is true of nearly all important advances ,was not without its controversies. This is similarly true of the developments in filters and balancing networks which Professor Pupin also mentions. Any reference to these past controversies is entirely aside from the purpose of the paper.

Now, about that part of Dr. Pupin's discussion relating to the beautiful companionship of the loading invention and the repeater invention, a casual reading of the paper may lead one to infer that the application of repeaters to loaded circuits was easily accomplished. Be it understood, however, that the paper is a statement of end results, rather than a detailed account of the difficulties which had to be overcome to reach these results; in fact a great deal of investigation was required, extending over a number of years, before it was commercially possible to combine phantoming, loading, and repeatering telephone circuits. A study of the line characteristics indicated that the failure of the early types of loading coil to maintain the necessary stability was principally responsible for the inability of the repeaters to get along with the loading coils. Development of new magnetic materials and improved construction methods were required before these obstacles were overcome.

METHODS OF HIGH QUALITY RECORDING AND REPRODUCING OF MUSIC AND SPEECH BASED ON TELEPHONE RESEARCH[1]

(Maxfield and Harrison)

New York, N. Y., February 9, 1926

C. R. Hanna: The following discussion applies particularly to that part of the paper dealing with the reproducing mechanism. The relative merits of the several improvements that were made are not clearly brought out in the paper and it is the purpose of the writer to compare the importance of the various developments.

In listening to reproduction from one of the new-type phonographs, the average person is impressed with just two things; first, the apparent greater volume of sound, and second, the great improvement in the response at low frequencies. The greater volume of sound is due partly to the fact that there are more low frequencies present, and perhaps, in a measure,

1. A. I. E. E. Journal, March, 1926, p. 243.

to the fact that the diaphragm is one which acts like a piston, causing a greater volumetric rate of displacement of air into the horn for a given needle velocity than with the old type of flat diaphragm.

The improvement in the low-frequency characteristic of the reproducer, as described, could not have been obtained without the use of the slowly expanding logarithmic or exponential horn. The authors refer to the work of Arthur Gordon Webster in this connection: the general properties of the exponential horn were given in his National Academy of Science paper of 1919. Webster did not, however, carry his work sufficiently far to show the properties which the authors have stated in their paper; namely, that the exponential horn is a uniform radiator of sound down to a certain frequency, known as the cut-off frequency, which is determined by the rate of increase of section and the area of the large end of the horn.

The authors cite some work (as yet unpublished), by Messrs. Flanders and Thuras, in which these properties are shown both theoretically and experimentally. I desire to call attention to the fact that the paper by Hanna and Slepian on "The Function and Design of Horns for Loud Speakers"[2] showed these same properties for the exponential horn. The equation for such a horn is

$$A = A_o \epsilon^{Bx}$$

where

A = Area at any point

A_o = Initial area

x = Distance from initial area, cm.

B = Constant which determines the rate of increase. It was demonstrated that the cut-off frequency is determined by the relation

$$\frac{2\pi f}{B} = \frac{a}{2}$$

where a = velocity of sound. From this it is seen that the smaller B is, the lower will be the cut-off.

The radiation characteristic of the infinite exponential horn

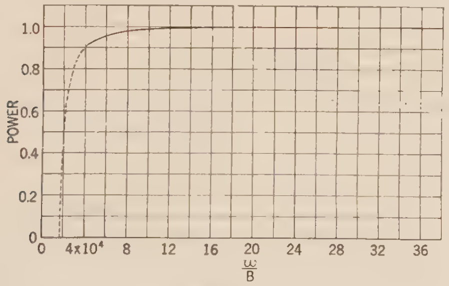

Fig. 1

for a fixed velocity of air in its throat was also shown in the paper by Hanna and Slepian. Fig. 1, herewith, shows this curve. The abscissas are $\frac{\omega}{B}$ and the ordinates give the comparison between the exponential horn and the infinite straight pipe which is a uniform radiator down to zero frequency. The cut-off point is seem to be as stated above.

It was clearly brought out in this paper that an exponential horn could be made with much smaller dimensions than any other shape of horn giving equal performance. A comparison was also shown between a particular exponential horn and a conical horn of equal length and terminal dimensions. This is given in Fig. 2, the superiority of the exponential horn being quite pronounced. Up to this time many persons had advocated the conical horn. It is believed that this paper was the first to show the superiority of the exponential horn.

2. A. I. E. E. Transactions, 1924, page 393.

Now, taking up the matter of the final or large area of the horn, as is pointed out by Maxfield and Harrison, if this area is large enough to prevent end reflections in the range of frequencies where the horn is a good radiator along its length, a horn will be secured which has very little resonance. The curves of Fig. 3 were presented by Hanna and Slepian to show the variation of reflection with frequency and area. The curves indicate that the smaller the area and the lower the frequency, the greater will be the reflection. It is seen, however, from the curve for

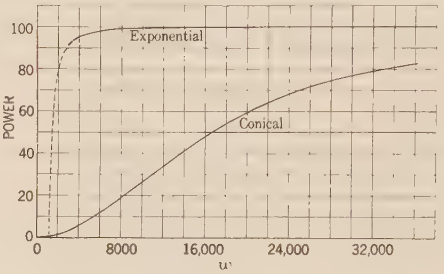

Fig. 2

the largest area, that the reflection becomes appreciable only in the range of frequencies where the horn ceases to be a good radiator along its length. Hence it follows that a horn of this shape can be designed with no marked fundamental resonance.

The degree of horn resonance and the position of the cut-off frequency as indicated by Fig. 20 of the Maxfield and Harrison paper agree very closely with values that can be predicted from the curves of Figs. 1 and 3 in this discussion.

The very careful proportioning of masses and compliances in the mechanical system of the reproducer has played only a minor part in the securing of a more uniform frequency-re-

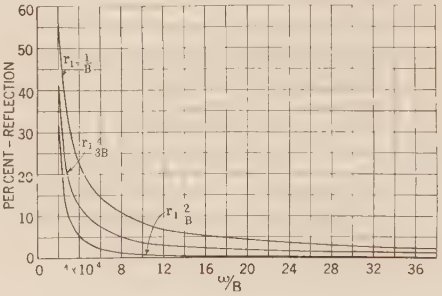

Fig. 3

sponse characteristic than in the older types of phonographs. The slight extension of the upper frequency range may be attributed to the accurate design of mechanical parts. It should be pointed out, however, that since the phonograph record is a constant-current (or velocity) generator, the impedance of the mechanical system does not have to be uniform over a wide band of frequencies for it to be forced to vibrate in accordance with the vibrational velocity of the record. A departure from this fact, not apparent from the electrical analogy given by the authors in their paper, is the ability of the whole arm of the reproducer to vibrate in the low-frequency ranges instead of just the diaphragm mechanism. This may be overcome either by increasing the mass of the arm or, as the authors have done, by reducing the stiffness of the diaphragm.

Great credit is due the authors for the design of a mechanical system which is light and resilient, enabling the needle to track the record with small reaction force (and consequent decrease in wear) at the high frequencies where the accelerations are great, and at low frequencies where the deflections are great. The big improvement in the quality of reproduction, however, is due to the use of an exponential horn whose rate of increase

of section is very small and whose final section is quite large.

E. W. Kellogg: I think most of us have thought of the rocking arm, which connects the needle with the diaphragm in a phonograph, as a simple lever, rigid enough so that when the needle moves one way, the diaphragm moves the opposite direction by a corresponding amount. If we could see what is really going on during a high-frequency vibration, we should probably find that the motion was more nearly like that of a snake. Messrs. Maxfield and Harrison and their associates have accepted the wave-motion picture and based their design upon it. The most striking resultant change in design is the interposition of a flexible link, or spring, between the end of the lever and the diaphragm. On first thought, it seems like deliberately throwing away some of the available motion, but the result is quite the opposite. I refer to the spider through which the diaphragm is driven.

If telephonic currents are to be transmitted without distortion over a high-efficiency line of length exceeding a sixth of a wavelength for the highest frequencies, the line must end in a non-inductive resistance of a definite value. A corresponding resistance is required in a mechanical system. In the case of the reproducing system the required resistance is obtained from the sound radiation of the diaphragm. But for the cutting tool, some other resistance must be found. In an electrical circuit nothing is easier to get than resistance, yet its mechanical counterpart is by no means easy to obtain. Sliding friction is not at all suitable. Motion in viscous fluids and electromagnetic drag, such as used in wattmeters, are true analogs. I wish to draw an illustration from the case of electromagnetic drag. An aluminum ring, weighing about four grams, surrounds a magnet pole, so that it is in a radial field of about 10,000 gausses. If one pushes it up and down, it feels as if it were in thick molasses. Under its own weight it settles about one millimeter per second. Yet if this ring is vibrated in an axial direction at 4000 cycles, its mass so predominates over the resistance that the power factor is only about 40 per cent. Mechanical hysteresis is another means for absorbing energy from vibrations. Rubber has long been used for such purposes. But rubber, so far from being pure in mechanical resistance, is a spring with a power factor of only about 10 per cent. I think the authors of the paper are to be complimented upon the ingenious device by which they obtain with the use of rubber a practically pure resistance with which to load the cutting tool. It should be borne in mind that the damping required for the cutting tool is of an altogether different order of magnitude from that which many of us have employed to take out the resonance peaks from loud-speaker diaphragms and similar applications.

The paper mentions methods of measuring mechanical impedances. I should be much interested to hear something further of the means used, for the problem presents many difficulties, and the results of such measurements would find many applications.

One statement in the paper causes considerable surprise. The knife edge was discarded because it has too great an elastic yield, and because it brings in too much rotational friction. The knife edge, of course, must work with an initial pressure exceeding the maximum force on the bearing, due to the vibrations, and is not well adapted to stand forces in more than one direction, but, in the case of the pivot for the reproducing lever, one would expect a well designed knife edge to work very satisfactorily.

L. T. Robinson: I am in agreement with the statement of the authors that, "There is therefore no distortion in the record whose purpose is to compensate for errors in the reproducing equipment." In employing so many elements, some of which can be so readily modified in performance the temptation is very strong to look only at the final result and not be too critical as to where any corrective treatment is to be administered. I hope the stand taken by the authors will be firmly adhered by them and others who are working along similar lines. In this way, any progress that has been made, or will be made, becomes permanent.

Speaking of the electrically-cut record in general, we need not, for the moment, be concerned with minor details of the process. The results already obtained are so good that we may feel sure that the electrically cut record has come to stay and will place the phonographic art on an entirely new plane of excellence.

The mechanical reproducing system described by the authors is a distinct advance over former phonographs. However, I feel that full realization of the advantage of the electrically cut record will come through electrical reproduction.

One great advantage of the electrical method of reproducing is that the control of the sound volume is obtainable quite independent of the cut on the record and the cut on the record is controllable with consideration for the best conditions for the record alone. The advantages of such separation can be learned from the paper if it is read with this point in mind.

Volume of the sound reproduced is quite important and reproduction to be quite satisfactory must be about equal to the volume of the original sounds. A loud tone produced on a given musical instrument is quite different from a soft tone produced on the same instrument and reproduced with larger volume.

A. E. Kennelly: We have here presented to us the wonderful analogy which underlies mechanical and electrical phenomena, with mechanical phenomena interpreted in electrical terms.

We have long known that mechanical inertia was really electrical, and now we are finding that all these mechanical phenomena are primarily electrical quantities.

J. P. Maxfield: There are one or two technical questions brought out in Mr. Hanna's discussion which are of interest: The first deals with the statement that the new reproducing mechanism has a greater apparent volume of sound. In this connection, it is interesting to note that the response curves of the new and the old machines shown in Fig. 20 indicate that in the frequency region from around 800 to 2000 cycles per second, the old machine produced a louder sound for a given needle velocity. It will be seen, therefore, that this apparent increase in volume has been obtained by the widening of the band reproduced rather than by increasing the amount of energy radiated in that frequency band in which the old machine was most efficient.

The other point of interest refers to his statement that "The very careful proportioning of the masses and compliances in the mechanical system of the reproducer has played only a minor part in the securing of the more uniform frequency response characteristic than in the older type of phonograph." In view of the high quality which is obtained and of the commercial requirement that the wear on the record shall not be excessive, the authors do not agree with this statement. It is not necessarily true that because the record is a constant-current generator and, therefore, delivers constant current to the sound-box mechanism, that the diaphragm necessarily delivers constant current to the air. If a relatively stiff, heavy, vibrating system is used, it becomes exceedingly difficult with the constant-current type of generator to obtain good quality and if it is possible to obtain it, the wear on the record becomes excessive. A reference to Fig. 16 indicates that the first part of the system reached is the needle point which has a definite compliance. At the higher frequencies, if the impedance of the reproducing system is too high, the needle will bend instead of moving the rest of the system and the response will be reduced thereby. Similarly, at the low-frequency end, if the diaphragm-edge compliance is too small, that is, if the diaphragm is too stiff, the whole tone arm will vibrate and thereby reduce the motion of the diaphragm relative to its case. It is true that, so far as response is concerned, this effect can be corrected by increasing the moment of inertia of the tone arm—a method which is equivalent to increasing the mutual inductance of the transformer, T_1, (Fig. 16); but if the solution is thus obtained, the wear on the record becomes excessive and in some cases the force becomes so great that the needle will not track in the groove.

The solution presented in the paper is one in which the mechanical impedance has been made as nearly as possible independent of frequency and is of the nature of a pure mechanical resistance. The result of this type of solution is that a maximum of sound energy at all frequencies within the band is radiated with a minimum of wear on the record.

MECHANICAL FORCE BETWEEN ELECTRIC CIRCUITS[1]

(Doherty and Park)

New York, February 9, 1926

J. Slepian: The relation which is perhaps most frequently used by electrical engineers for calculating mechanical forces between circuits is that due to Maxwell, which states that, in any displacement in which currents are kept constant, the mechanical work received during the displacement is equal to the increase in magnetic energy of the system. This relation is readily derived from the principle of conservation of energy by taking into account the electrical input during the displacement. As Professor Karapetoff puts it, there is a "fifty-fifty" rule here; half the electrical input goes to increasing the magnetic energy and half is given up to mechanical work.

However, this fifty-fifty rule does not apply when there is iron in the neighborhood, subject to saturation, and Messrs. Doherty and Park do well to bring out this fact strongly. In my own experience I have seen several cases where this rule led to completely erroneous results when applied to practical machines. In one instance, a complete change in sign of the force was involved, a repulsion was predicted, whereas actually an attraction was found. The magnetic circuit shown in Doherty and Park's Fig. 1 is one for which application of the fifty-fifty rule would give the wrong sign if the iron is saturated. With constant current, motion of the armature upward *decreases* the magnetic energy, and yet, the armature is attracted and not repelled.

The great contribution of Doherty and Park in this paper lies in showing that application of the principle of conservation of energy in another way leads to a relation which is universally applicable, saturation or no saturation. Namely, if the mechanical displacement is effected, not with constant currents but with constant flux linkages, then the mechanical work received is equal to the *decrease* in magnetic energy. The authors further add to the value of this result by showing how the calculation on this basis may be carried out, when the curves connecting flux linkages with currents for various positions of the moving parts are known.

I have a suggestion to make as to the formulas (*9*) and (*11*) which the authors give, and the corresponding expression for magnetic energy. While it is principally a matter of notation, I think it is important because it makes such a difference in the clarity of ideas. For simplicity, considering only two circuits, the authors would write the magnetic energy,

$$E = \int_0^{\Omega_1} i_1 \, d\,\omega_1 + \int_0^{\Omega_1} i_2 \, d\,\omega_2$$

To bring out more definitely that i_1 and i_2 are functions of both variables, w_1 and w_2 I shall write this as

$$E = \int_0^{\Omega_1} i_1 \, (\omega_1 \, \omega_2) \, d\,\omega_1 + \int_0^{\Omega_2} i_2 \, (\omega_1 \, \omega_2) \, d\,\omega_2$$

Now ω_2 is not a constant in the first integral, but may be varied as ω_1 varies, and ω_1 is not a constant in the second integral. However, whatever relation is adopted between ω_2 and ω_1 in the first integral, the same relation must be used in the second if the correct value for magnetic energy is to be obtained.

Now integrals of this kind are of frequent occurrence in mathematical physics, and they are usually denoted by line integrals written thus:

$$E = \int_{\substack{\omega_1 = 0 \\ \omega_2 = 0}}^{\substack{\omega_1 = \Omega_1 \\ \omega_2 = \Omega_2}} i_1 \, d\,\omega_1 + i_2 \, d\,\omega_2$$

This single integration is to be carried out over a curve in the $\omega_1 \, \omega_2$ plane, joining the point $\begin{pmatrix} \omega_1 = 0 \\ \omega_2 = 0 \end{pmatrix}$ to point $\begin{pmatrix} \omega_1 = \Omega_1 \\ \omega_2 = \Omega_2 \end{pmatrix}$.

In general, the value of such a line integral depends upon the path chosen in going from the initial point to the final point, but in this case since the magnetic energy is the same, however the state $\begin{pmatrix} \omega_1 = \Omega_1 \\ \omega_2 = \Omega_2 \end{pmatrix}$ is reached, the integral is independent of the path. Mathematicians have shown that in this case it follows that

$$\frac{\partial \, i_1}{\partial \, \omega_2} = \frac{\partial \, i_2}{\partial \, \omega_1}.$$

This may be looked upon as a generalization for the case of saturation, of the well-known fact for the linear case, that the mutual inductance of circuit No. 1 upon circuit No. 2 is equal to the mutual inductance of circuit No. 2 upon circuit No. 1.

On the fourth page first column of their paper, the authors give a number of formulas applying to their Fig. 1, and state that the quantity L_0, which appears there, is the inductance corresponding to no saturation. However, in their derivation of these formulas, if I understand their derivation correctly, L_0 is taken as the inductance corresponding to the air gap alone. That is, L_0 is the inductance corresponding to infinite permeability, and not to no saturation. There thus seems to be an omission in the authors' proof, which might be rectified as follows.

Let

L_0 = inductance corresponding to air-gap alone: *i. e.* inductance corresponding to infinite permeability.

Let

L_0 = inductance corresponding to no saturation,

Let

L_1 = inductance corresponding to iron alone with no saturation, *i. e.*, inductance with zero air-gap and no saturation.

Then,

$$\frac{1}{L_0'} = \frac{1}{L_0} + \frac{1}{L_1}$$

Hence, since L_1 is constant.

$$\frac{\partial}{\partial \, x} \left(\frac{1}{L_0'} \right) - \frac{\partial}{\partial \, x} \left(\frac{1}{L_0} \right)$$

Hence, since L_0 appears in the authors' formulas only in the factor

$$\frac{\partial}{\partial \, x} \left(\frac{1}{L_0} \right)$$

Therefore L_0' may replace L_0 throughout.

R. H. Park: In order to test the ease of applicability of the formulas developed and the agreement of calculated and observed results, a calculation and test was made in a particular case.

The circuit employed (see Fig. 1 herewith) consisted of two magnetic yokes separated by a brass strip and excited by direct current in two coils connected in series.

In order to determine the attractive force of the yokes, a weight was attached to the lower yoke and the exciting current was reduced until the yokes separated.

In order to calculate the force, the flux linkages ω were measured with a ballistic galvanometer for different air-gap and excitation. This data are shown in Fig. 2.

From the saturation curves, the curves of $\frac{\partial \, i}{\partial \, x}$ at constant ω were computed (see Fig. 3) as outlined in the paper. The forces were then calculated from the areas under these curves.

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1. A. I. E. E. Journal, March, 1926, p. 231.

The agreement of observed and calculated results is shown in Fig. 4. The smooth lines in the figure represent the calculated, and the small circles, the observed results.

The difference between observed and calculated results is about 4 or 5 per cent, the observed results being, in general less than the calculated. The tendency for the observed results

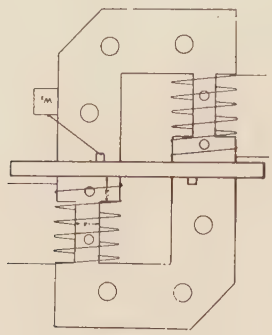

Fig. 1

to be low may be accounted for by unavoidable disagreement in the positions of the center of moment of the load and of the attractive force resulting in less effective magnetic pull, or by the effect of vibration.

From a theoretical point of view, we know that, until the satura-

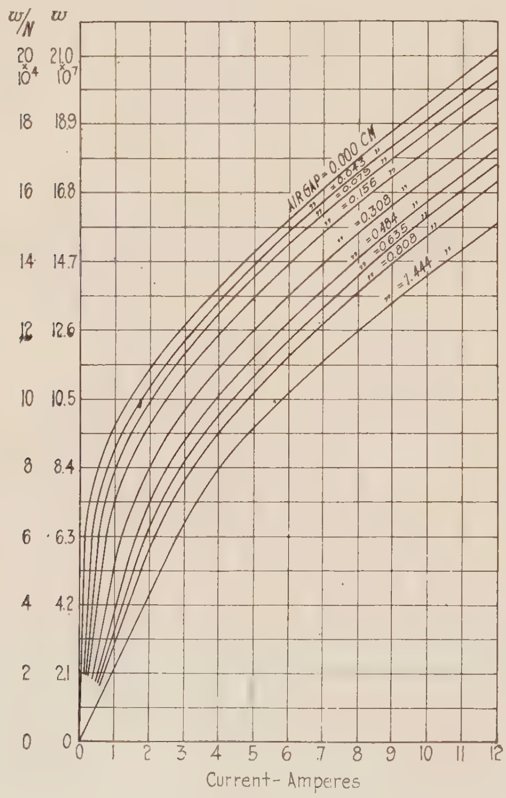

Fig. 2

tion of the core is sufficient to change appreciably, the distribution of the field in air, the curves of $\frac{\partial i}{\partial x}$ should be linear.

It may be observed that the experimental results agree with this requirement, the curves of $\frac{\partial i}{\partial x}$ being linear except at very high saturation.

This fact indicates that the approximate expression for force [equation (**65**) of the paper] holds good in this case until extremely high values of saturation are encountered.

Thus, the experimental results obtained agree with those theoretically deduced in the paper.

R. E. Doherty: The authors wish to thank Dr. Slepian for his

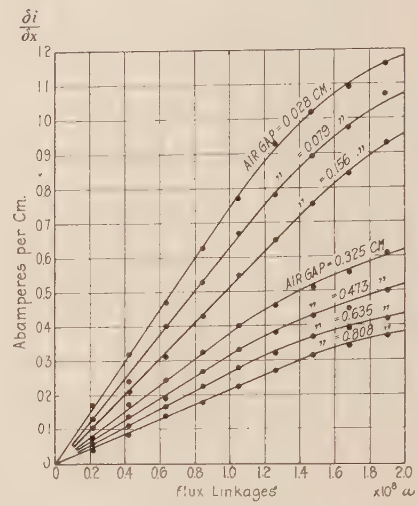

Fig. 3

suggestion regarding notation. It is undoubtedly a somewhat clearer representation of quantities than that used by them.

With respect to his other suggestion, however, the authors have not made the omission in logic which he alleges.

They have treated two different *special cases* where saturation

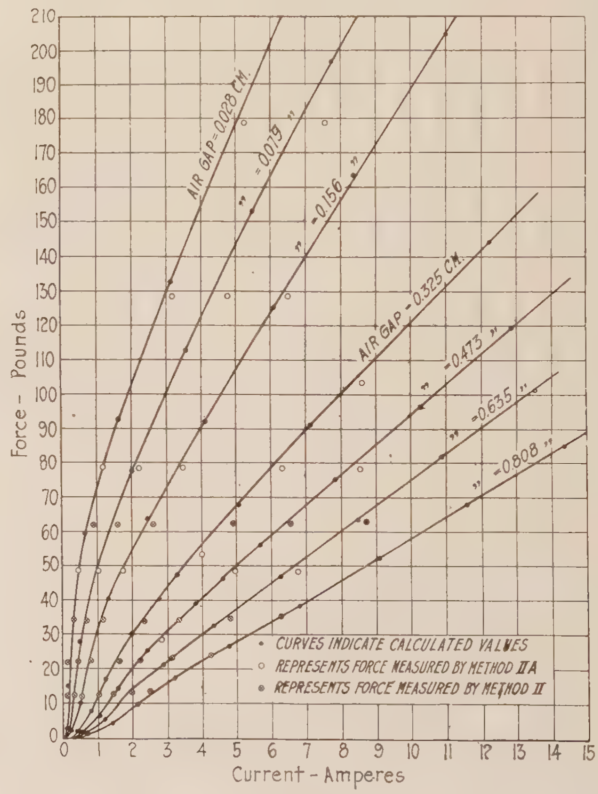

Fig. 4

is taken into account, and in the results of both cases, the term L_0 appears. The symbol L_0 is defined in the list of notations as "the self-inductance in henrys of a single circuit without satura-

tion," and it therefore, in general, includes the effect of the reluctance of the iron as well as of the air. Dr. Slepian's point is that the effect of the reluctance in the iron, when saturation is absent, is not taken into account.

The two cases treated are,

a. "Special Case," in connection with Fig. 3 of the paper. Here it is specifically stated that, so far as L_0 is concerned, the magnetic reluctance of the iron is neglected. Therefore L_0 in this special case in the industance corresponding to zero reluctance in the iron. Hence Dr. Slepian's discussion, referring to the equations based on this assumption, is not pertinent.

b. Another case, Appendix D, in which no qualifying assumption is made with respect to L_0 except those given in the definition, quoted above, from the list of symbols. And, therefore, if it is desired to consider the case which Dr. Slepian has in mind, he should use the equations for this case given in Appendix D.

PARAMETERS OF HEATING CURVES OF ELECTRICAL MACHINERY[1]

(Karapetoff)

New York, N. Y., February 10, 1926

G. E. Luke: As mentioned in this paper, Professor Kennelly derived the heating characteristics of an electric machine by considering it as one "chunk" of metal[2]. This paper gives the thermal equations on the basis of two "chunks" of metal (core and windings). An approximate solution of this problem based on three "chunks" of metal (core, windings, and frame) was given in another previous Institute paper[3]. As a matter of fact, a correct solution of this problem would have to be based upon an infinite number of "chunks."

Professor Karapetoff assumed two thermally connected masses of metal (core and windings), each having a uniform temperature and loss throughout. In practise, the losses and temperatures are usually much higher in the teeth than in the main part of the core; hence, there will be a heat flow in that direction. In the windings, there may be a considerable heat flow from the embedded part to the ventilated end portion. Thus, the heating curve of the "hot spot" on the copper will depend not only upon the thermal constants of the embedded copper and core but also upon the thermal conditions of the end windings. Again the large variation in the temperature of the cooling fluid in its passage through the machine will tend to cause all parts of the machine to vary with it.

The assumptions which must be made in order to derive the approximate thermal characteristics of a machine are more closely approached in small machines with relatively little forced cooling. On the other hand, in large machines, where long heat and fluid flow paths are found, together with a high velocity of the cooling fluid, the derivation of the heating characteristics on the assumption of uniform core and winding temperatures is likely to be erroneous.

The method of solution of the problem as simplified by Professor Karapetoff interested me, as several years ago I had occasion to solve the same problem. In my solution, θ_1 was evaluated from eq. (2) (also $d\,\theta_1$) and substituted in eq. (1). This also gave a linear differential equation having constant coefficients, but the second member, instead of being zero, as in eq. (8), was a function of p_1, p_2, k_1, k_2, s_1, and α, where α is the temperature coefficient of resistance. The solution of this was similar to eq. (10) with a constant term added. Although the method of solution given in this paper seems to be indirect, yet the equations representing the arbitrary constants are more systematic than the method I used.

For the application of these equations, the author suggested that the many constants be calculated from experimentally obtained heating curves. The difficulty is to obtain accurate heating curves of the copper and iron temperatures especially on the rotating members.

I have applied these equations for predetermining the temperatures of machines on short-time overloads by calculating the constants from the known physical conditions. Thus, on such loads, most of the losses are stored and since the copper has such a high rate of loss, its temperature rises quickly. For example, the temperature rises of a 50-h. p., d-c. railway motor on a 150-per cent load, for one-half hour, as calculated (starting cold) were 51.5 deg. cent. armature core and 85.5 deg. armature copper, while the actual tested values were 48.0 and 87.5 deg. cent. respectively.

Another interesting application of these heating equations was to calculate the heating and cooling curve of a 600-volt, 31,000-cir. mil., rubber-insulated, stranded copper cable, with a

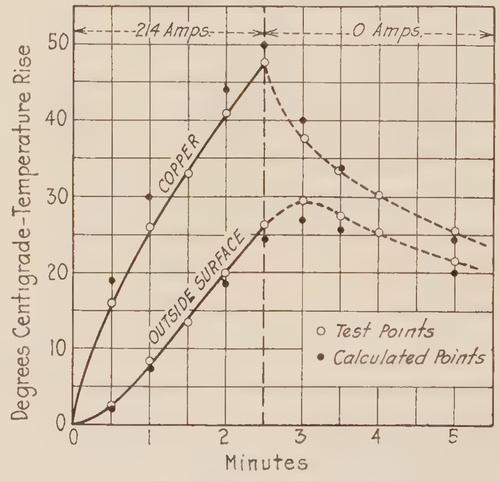

Fig. 1—Heating and Cooling Curve of a 600-Volt, 32,000-cm. Rubber-Insulated, Stranded Copper Cable

load of 214 amperes for 2½ min. The calculated points were based only on the weight of copper and insulation, the conductivity of heat of the rubber, and the surface heat transfer from the cable. The solution is necessarily approximate since the insulation and copper were assumed to have a uniform temperature θ_2 and θ_1, respectively. The results are given in Fig. 1 herewith. Since the loss in the rubber was zero, its slope was zero at the start of the cycle.

Although the assumption of two thermal masses simplifies the problem considerably, the final solution is still long and complicated and therefore will be used seldom by the average engineer. This solution should prove of value to the specialist, however, when considering problems such as I have mentioned. This solution also will indicate the limitations and errors of the less approximate solution based on a single uniform mass of metal.

W. F. Dawson: I want to show some curves (Fig. 2 herewith) that follow the curves given in Goldschmidt's paper[4] and also by Dr. Kennelly.

These curves are the heating curve of a mass of copper imbedded in insulation and other surrounding material. To simplify the problem, let us assume that it is not armature copper in an armature, but a field coil where the only loss is the copper loss. The initial rate of temperature rise depends upon the specific heat of the material, the specific gravity, (density), the specific resistance, and the current density. It so happens that, at 1100 amperes per sq. in., where there are no parasitic or extra losses, and the mean temperature is about 60 deg. cent., the rate

1. A. I. E. E. Journal, January, 1926, p. 40.
2. Temperature Rise of Electric Machines on Intermittent Duty, by G. E. Luke, *Electrical World*, May 27, 1922.
3. *Heating of Railway Motors in Service and Test-Flaor Runs*, by G. E. Luke, Journal A. I. E. E., (1922), p. 165..

4. *Journal* I. E. E. (London) May 1905, Vol. 34, No. 172, p. 660.

of temperature rise is almost exactly one deg. cent. per min. This current density also gives approximately one watt per cu. in. (0.95 watt).

In practise, it is found that at 1100 amperes per sq. in., the initial rate of temperature increase is much less than one deg. cent per min., seldom more than one-half of a deg. cent. per min. and sometimes as low as one-third of a deg. cent. per min. The explanation lies in the fact that these windings are always surrounded with a considerable amount of insulation and frequently with masses of iron. Goldschmidt has suggested that the specific heat of cotton insulation is approximately six times that of copper; hence it is easy to explain that the added thermal capacity of the surrounding insulation and iron is responsible for the lowered rate of temperature rise. A divisor of two is usually quite safe, hence with a current density of 2200 amperes per sq. in., one can safely assume that the initial rate of temperature rise will not exceed two deg. cent. per min.

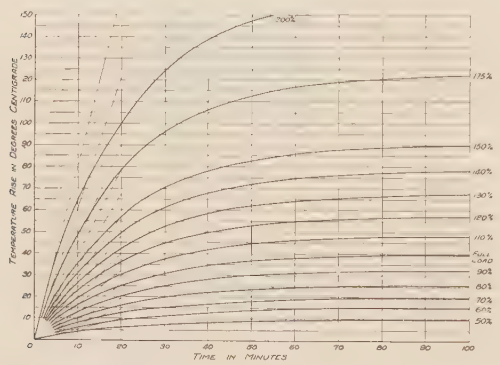

FIG. 2—TEMPERATURE GRADIENT CURVES BASED ON 2200 AMPERES PER SQ. IN., FULL LOAD AND TWO-DEG. RISE PER MIN.

I have made several tests with temperature rise plotted against time and found that, when a proper factor was used for the thermal capacity, the test results compared very closely with curves calculated according to Goldschmidt's formula. In one, a strange "hump" was shown in the observed heating curve and it was referred back to the testing department with the comment that "the phase currents in the armature became temporarily unbalanced." This was found to be the case. The extra heating was due to double-frequency currents induced in the field because currents in the armature phases became unbalanced. Fig. 2 will be found useful in the study of short-time ratings of windings, and the effect of fractional loads and overloads. It should be considered as a suggestion rather than something to be followed under all circumstances. It is plotted on the assumption that 2200 amperes per sq. in. gives an initial temperature rise of two deg. cent. per min. (this assumes that total thermal capacity equals twice that of the copper winding), that the final temperature rise will be 40 deg., and that the temperature rise varies as the square of the current load.

A little study will suggest many uses for curves of this sort; for example, a short-time overload is required on a machine that has been operating at fractional load until it has reached steady temperature. From the steady temperature indicated by the curve for that fractional load, follow the abscissa line to the left until it intersects the curve corresponding with the overload and note the corresponding time. Add the time for the required overload, and the intersection of the corresponding ordinate with the overload curve will indicate the total temperature rise.

C. J. Fechheimer: A few more words may be added in regard to the longitudinal heat flow in the copper. In machines which have, let us say, over 50-in. core length, the influence of the longitudinal flow upon the copper temperature at the middle of the core may be neglected. But in short machines, that flow plays an important part in the heat dissipation at the center. In some short machines, (say eight in. of core length or less), most of the heat generated in the copper is dissipated from the end windings, and there may even be flow of heat from the iron to the embedded copper whence it flows longitudinally to the ends. Frequently, then, there is not a great difference in temperature between the embedded copper and the ends.

It is well known that the time constant in a simple exponential equation is proportional to the ratio of the storage of heat to the dissipation of heat. In general, that time constant is considerably higher for the embedded part than for the ends, and, since there is so large an interchange of heat between the two in the short machine, the influence of the longitudinal flow cannot be ignored. About eight years ago I tried to obtain a solution of the problem, taking into account time and the distance along the conductors as independent variables. I obtained the partial differential equations and was able to integrate them. But the equations became so unwieldy when the terminal conditions were substituted that I abandoned the solution. I believe I still have the papers, and should be glad to send to Professor Karapetoff the results as far as I went, if he cares to go over them.

Suppose the time-temperature curves for a short machine are illustrated graphically as in Fig. 3 herewith. Curve I shows the rate of heating of the embedded part, and Curve II that of the ends, assuming that neither is influenced by the other. The actual time-temperature curve of the copper at the middle of the machine is about as in Curve III. The ends attain their maximum temperature in considerably less time than the embedded parts, each acting alone, and the maximums are quite different.

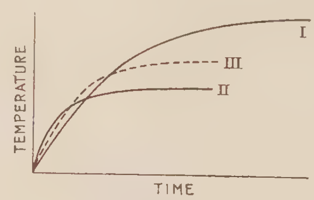

FIG. 3

If the equation of Curve III can be taken as of simple exponential form $[\theta = \theta_o (1 - \epsilon^{-\frac{T}{t}})]$, and if the final temperature rise θ_o and the initial slope $\left(\frac{d\theta}{dt}\right)_{t=o}$ be known, the entire curve can be plotted.

In Dr. Kennelly's paper of last year, and in this paper of Professor Karapetoff's mention is made of the similarity between the time equations of the heat circuit and the electric current containing inductance and resistance. In the discussion of a paper by Mr. Luke in 1922, that similarity was noted.[3] Perhaps that was brought to the attention of the electrical engineers long ago.

A. E. Kennelly: In the paper which I presented last year, I was not interested primarily in the determination of the conditions of heating, but in the presentation of the statistical factors concerning heating. As has been pointed out by several speakers, and as pointed out in the discussion last year, there are a number of instances in which the heating curves of parts of machines, or of parts of windings, or of core bodies, follow exponential curves,

and it is marvelous, I think, how common exponential curves, either of the rising type or of the falling type, are in natural phenomena.

We have been in the habit of referring the unit of time in which the exponential change occurs to a time constant in which the change is 63.2 per cent of the final ultimate change and in the next time constant 63.2 per cent of what again is left. That is a very awkward numerical calculation to present to practical men, so that, in order to avoid that unnecessary numerical and statistical combination, I ventured to point out that it is sufficient to take approximately 70 per cent of that exponential time constant (69.3 per cent theoretically) and to state that, as the binary time-constant or the time to come up to one-half; so that if in the first binary time constant of, let us say, twenty minutes, this element of the machine will come to half its final temperature elevation, then, in the next binary time constant of twenty minutes, it will come to half of what is left or three-quarters of the whole.

As has been pointed out by Professor Karapetoff and others, probably no machine develops a strictly exponential time curve of heating. As engineers, we try to find reasonable practical applications and we say, "Well, granted that it is never quite true, are there not cases which present themselves where the deviations for ordinary practical purposes can be neglected?" It is my opinion, after having gone over a considerable number of such heating curves, that many cases can be treated upon the basis of an experimental time constant.

So I think the procedure we can agree upon is this: Let us find the cases which present themselves in engineering practise where the actual curves are nearly constant, so that we may say, for practical purposes, that this machine, under such a load, will come up to one-half its final temperature elevation in so many minutes. Then one knows just how the heating will be beyond that point. Then, let us tabulate the exceptions.

I think we may look upon this as a valuable tool for the future, but I want first to see a tabulation of what can be done with existing machinery of various classes, using the simple, single time-constant. From what I have been able to ascertain from actual engineers,—men who are using this,—there will be a considerable number of cases where that does apply reasonably well.

F. Fabinger (in writing[5]): It may be of interest to call attention to my article entitled "A Contribution to the Theory of Heating of Electrical Machinery" published in the May 1923 issue of the *Elektrotechnicky Obzor* which is the official organ of the Association of Electrical Engineers of Czechoslovakia. In this article, I consider a body which is a source of constant quantity of heat per unit time to be completely surrounded by another body of infinite conductivity, in contact with a cooling medium of constant temperature. The differential equations in this case lead to a solution similar to Karapetoff's eq. (**10**); that is, the instantaneous temperature is expressed by a sum of two exponential terms.

Vladimir Karapetoff: As Dr. Kennelly has pointed out, the next step is to apply the proposed theory to a few machines to see how handy (or unhandy) it will be. I also hope that someone will be spurred to improve the two-chunk theory, but let us hope that this will be not in the direction of a three-chunk theory, but in the direction of distributed flow of heat.

To me, the next step is this: Assume the heat flow in the stator copper to be parallel to the shaft of the machine and the heat flow in the stator core to be radial. The temperature at a point will then not only be a function of time, but of the coordinates of that point as well, so that, as Mr. Fechheimer has pointed out, we shall have equations with partial derivatives. It would be of considerable interest to establish such equations. Even should they prove to be too complicated for a straightforward solution, some approximation methods may be applicable in numerical cases.

5. From Prague, Czechoslovakia.

ILLUMINATION ITEMS

By Committee on Production and Application of Light

SMALL CORONA LAMPS

Gaseous conductor lamps have been produced by D. McFarlan Moore for service on 115-volt circuits and in sizes smaller than those heretofore developed. They are now available in two sizes, illustrated in the accompanying cut, for operation upon 115-volt circuits, a-c. and d-c.

The lamps are understood to be filled with neon, argon and helium in certain proportions. When excited by electric pressure, the gas becomes luminous at the cathode. On direct current, the gas around one electrode glows. On alternating current, the gas glows at both electrodes.

The round bulb lamp, which is little more than an inch in diameter, consumes approximately 1/10 watt with an efficiency of the order of ¼ lumen per watt. The small tubular bulb lamp consumes about 1/50 watt.

These lamps, because of their low illuminating power and low efficiency, are not employed for purposes of illumination but possess value as markers and signal lights. By reason of practically instantaneous lighting and extinction characteristics they possess peculiar value for stroboscopic use. This type of lamp is employed in successful experimental transmission of motion pictures.

At the Annual Convention of the Institute at White Sulphur Springs, in discussion of these lamps, it was suggested that one field of application for them lies in their use as signal lamps on motors for direct drive in industrial work where 220-volt supply circuits necessitate the use of 220-volt lamps which oftentimes are not easily available.

EYESIGHT CONSERVATION

The investigation of school architecture and construction showed that defective illumination of classrooms has an adverse influence on the activity of the intellectual processes of children.

The investigators, according to the report of the Eyesight Conservation Council, studied the relative value of daylighting and artificial lighting, concluding that "owing to the manner in which the human eye has developed during many ages under natural lighting conditions, the great changes in the intensity of daylight, varying as much as 1,000 foot-candles and more within a few minutes, are less trying to the eye than are the variations of relatively few foot-candles of artificial light."

The standards used in the U. S. investigation were those of the Code of Lighting School Buildings prepared jointly by the Illuminating Engineering Society and the American Institute of Architects and approved as an "American Standard" by the American Engineering Standards Committee, on which the Eye Sight Conservation Council was represented. This code makes definite provisions for natural as well as artificial lighting. (Eyesight Conservation Council of America.)

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The Institute is not responsible for the statements and opinions given in the papers and discussions published herein. These are the views of individuals to whom they are credited and are not binding on the membership as a whole.

Annual Convention, White Sulphur Springs

As we go to press, the Annual Convention of the A. I. E. E. is being held at White Sulphur Springs, W. Va., June 21-25 inclusive.

The program is comprehensive of many interesting and progressive aspects of the Institute's activities furnishing many attractions for the 350 engineers in attendance.

The various committees of the Institute have surveyed the advancement of the profession in their respective fields; President Pupin, President-elect Chesney and other notable leaders have contributed addresses on the developments in electrical engineering, emphasizing the need and desirability of the electrical engineer participating both individually and collectively in national as well as local affairs. Several high-grade technical papers were scheduled for presentation, presenting gratifying advancement in the field of this specific art, as well as leading to much valuable and pertinent discussion.

The full report of the Convention will appear in the August issue of the JOURNAL.

Pacific Coast Convention to be Held in Salt Lake City, Sept. 6-10

This year the Pacific Coast Convention will be held in Salt Lake City, Utah, beginning September 6 and continuing through for four days. A number of very fine papers have been arranged for and the well-known hospitality of Salt Lake City and the points of interest in and nearby this city insure an enjoyable meeting.

The technical papers will deal with such subjects as high-voltage transmission, corona, surge recorders, stability of alternators, distribution stations, the growth of population, power-factor correction, protection of oil tanks against lightning, transcontinental telephony, carrier communication on submarine cables, electricity in lead-silver mines, safety in mine application and engineering education.

The general committee in charge of arrangements for the meeting is as follows: C. R. Higson, Chairman; P. P. Ashworth, H. G. Baker, V. L. Board, D. L. Brundige, R. J. Corfield, G. S. Covey, John Harisberger, R. A. Hopkins, C. P. Kahler, J. A. Kahn, E. A. Loew, C. A. Malinowski, J. F. Merrill, E. B. Meyer, H. T. Plumb, R. C. Powell, C. C. Pratt, Paul Ranson, L. W. Ross, John Salberg, H. H. Schoolfield, M. M. Steck, A. Vilstrup, H. B. Waters and B. C. J. Wheatlake.

A Fine Niagara Regional Meeting

A regional meeting of outstanding accomplishment was held by the Northeastern District of the Institute at Niagara Falls, N. Y., May 26-28. The meeting was notable for excellent papers, earnest discussion, well attended sessions and entertainment of high grade. About 580 attended the meeting. All sessions were held in the Niagara Hotel, the convention headquarters.

The meeting was opened on Wednesday morning, May 26, by Prof. H. B. Smith, Vice-President in the Northeastern District, after which J. A. Johnson, Chairman of the local convention committee, welcomed the assembled members in a short address. The first technical session, a symposiun on measurement of dielectric power factor, was presided over by Prof. A. E. Knowlton. Seven papers were presented which were as follows: *Phase Difference in Dielectrics*, by J. B. Whitehead; *Standards for Measuring Power Factor of Dielectrics*, by H. L. Curtis; *The Significance of Errors in Dielectric-Loss Measurements*, by C. F. Hanson; *Use of Dynamometer-Wattmeter for Measuring Dielectric Power Loss*, by E. S. Lee; *Commercial Dielectric-Loss Measurements*, by R. E. Marbury; *Three Methods of Measuring Dielectric Power Loss and Power Factor*, by E. D. Doyle and E. H. Salter and *The Dielectric-Loss-Measurement Problem* by B. W. St. Clair.

A full discussion followed to which the following contributed: P. L. Hoover, E. W. Davis, I. M. Stein, J. D. Stacy, D. DuBois, Brian O'Brien, N. L. Morgan and R. Notvest.

This symposium was continued on Wednesday afternoon with W. A. Del Mar presiding. Two papers were presented as follows: *Compensation for Errors of the Quadrant Electrometer*, by D. M. Simons and W. S. Brown; *Zero Method of Measuring Power with a Quadrant Electrometer*, by W. B. Kouwenhoven and P. L. Betz.

Discussion on these papers was given by J. B. Whitehead, H. L. Curtis, C. F. Hanson, E. S. Lee, E. H. Salter, D. M. Simons, B. W. St. Clair, W. B. Kouwenhoven, C. A. Adams and Delafield DuBois.

A delightful trip to Toronto was enjoyed by about 200 members, following the session on Wednesday afternoon. The party traveled by trolley down the Niagara Gorge to Lewiston and across Lake Ontario to Toronto on a lake steamer. At Toronto the steamer was met by the lady guests of the convention who had gone in the morning to Toronto, where they were entertained by the ladies of the Toronto Section. On the return trip across the lake dancing was enjoyed on one of the decks.

The Thursday morning technical session was opened by J. A. Johnson, the presiding officer and two papers on rectifiers were presented as follows: *Steel-Enclosed Power Rectifiers*, by O. K. Marti; *Rectifier Voltage Control*, by D. C. Prince. These papers were discussed by R. H. Wheeler, Otto Naef, F. A. Faron, D. C. Prince, E. B. Shand, and S. Q. Hayes.

E. F. W. Alexanderson next presented his paper *Polarization of Radio Waves* and this was followed by *Current Transformers*

with Nickel-Iron Cores, by Thomas Spooner. I. F. Kinnard and W. K. Dickinson discussed the latter paper.

K. B. McEachron then described informally some experimental work he has done on the calibration of Lichtenberg figures, and J. H. Cox also added some discussion on this subject. Two more papers were then presented, namely, *A Flux-Voltmeter for Magnetic Tests*, by G. Camilli, and *Circulation of Harmonics in Transformer Circuits*, by T. C. Lennox. These were discussed by R. L. Sanford, W. H. Cooney and C. H. Kline.

On Thursday afternoon inspection trips were made, the principal trip being a scenic trip in the Gorge on which stops were being made to inspect the power plants on both sides of the river.

The high point of the meeting was reached on Thursday evening in the banquet at which about 400 were present including a large number of Institute officers and other notables of the electrical profession. Vice-President H. B. Smith was toastmaster and he first introduced P. A. Schoellkopf, President of the Niagara Falls Power Company, who said a few words of welcome. He was followed in short addresses by Giuseppe Faccioli, past-vice-president in the Northeastern District, A. I. E. E.; F. L. Hutchinson, National-Secretary; H. M. Hobart, Vice-President-elect in the Northeastern District; C. C. Chesney, President-Elect of the A. I. E. E.; C. F. Scott, Past-President, and Edward D. Adams, one of the founders of the original power development at Niagara Falls.

Mr. Adams gave a most interesting account of the difficulties of starting the Niagara Falls development in 1890 and 1891. At that time, he recalled, polyphase electric power was virtually unknown in this country and the only alternating-current apparatus consisted of small single-phase belted generators. The decision to adopt alternating current was strongly opposed by such authorities as Edison and Lord Kelvin. However, it is now obvious that this decision is largely responsible for the remarkable advances made by the electric light and power industry for the success of Niagara has spread its influence over the earth. Niagara has stimulated and focussed attention on water-power development, electric transmission and the utilization of electricity. It is symbolic of engineering courage, daring and achievement.

Following Mr. Adams' address the winners of the prizes for papers presented in the Northeastern District in 1925 were announced by C. A. Stevens, secretary of the District executive committee. The prize for the "best" paper was awarded to K. B. McEachron and E. J. Wade for their paper *Study of Time Lag of the Needle Gap*. The prize for the best "first" paper was awarded jointly to C. A. Nickle and R. W. Wieseman,—their respective papers being *An Electro-Mechanical System Analyzer*, (Nickle) and *A Two-Speed Salient-Pole Synchronous Motor* (Wieseman).

The final event of the dinner was a lecture on *Modern Reproduction of Sound*, by L. T. Robinson. He talked particularly on the recording of sound on electrically cut phonograph records and reproduction by the phonograph. He illustrated his talk through the reproduction of several musical selections by means of a phonograph operating a loud speaker whose volume of sound filled the banquet room.

After the banquet a trolley trip was made to view the Falls which were being illuminated with many changing and shifting colors.

At Friday morning's session, H. C. Don Carlos in the chair, four papers were presented. The first was *Variable Armature Leakage Reactance*, by V. Karapetoff. This was discussed by P. M. Lincoln and E. B. Shand. J. A. Johnson and E. J. Burnham then presented *Fire Protection of A-C. Generators*. This was discussed by H. L. Barns, H. U. Hart, R. B. Williamson, L. W. Riggs, S. Q. Hayes, A. F. Hamdi, M. W. Smith, J. Allen Johnson, James A. Johnson and L. W. Riggs.

F. V. Smith then presented his paper *Automatic and Supervisory Control of Hydroelectric Stations* and this was discussed by W. H. Gerrie, C. F. Publow and A. G. Darling.

The paper *Retardation Method of Loss Determination as Applied to the Niagara Falls Generators* by J. A. Johnson was then presented. Those discussing it were R. B. Williamson, E. M. Wood, V. Karapetoff, O. K. Marti and W. J. Foster.

Friday afternoon's session on power transmission was presided over by P. H. Thomas. S. Q. Hayes first presented a lecture illustrated with slides on *Interconnection and Superpower*. Mr. Hayes showed the large interconnected systems in this and other countries. L. E. Imlay then presented a paper on *European Transmission Practises* by G. F. Chellis. Following this three more papers were presented, namely, *Lightning and Other Experience on 132-kv. Transmission Lines*, by M. L. Sindeband and P. S. Sporn; *Notes on the Vibration of Transmission-Line Conductors*, by Theodore Varney; *Transmission-Line Sag Calculations, by H. B. Dwight.* Extended discussion followed by F. W. Peek, L. E. Imlay, L. C. Nicholson, E. S. Healy, S. S. Hertz, M. G. Lloyd, H. B. Vincent, A. E. Knowlton, N. J. Neall, C. F. Scott, A. O. Austin, J. H. Cox, V. Karapetoff, and H. Halperin.

On Friday evening there were two interesting features. The first was a piano recital by Professor Vladimir Karapetoff who chose for his subject Wagner's opera Parsifal. Prof. Karapetoff made the rendition of the music especially attractive by a previous explanation of the story of the opera, by lantern slides showing principal events and by explanatory verbal interpolations.

The meeting ended with a lecture by G. S. Anderson on the *Present and Future Development of Niagara Falls* which was illustrated with beautiful motion pictures.

This, the third regional meeting held by the Northeastern District, was in all ways a success, and the committees in charge deserve the highest commendation for the organization of the meeting and the smoothness with which all the events were conducted.

Institute Award of Prizes

The Committee on Award of Institute Prizes, composed of Messrs. E. B. Meyer, Chairman of the Meetings and Papers Committee, L. F. Morehouse, Chairman of the Publication Committee and Percy H. Thomas, Chairman of the Power Transmission and Distribution Committee, reported on the date of June 15, as follows:

"The Committee on Award of Institute Prizes has carefully considered the various papers submitted during the year 1925. They are all of a high calibre and show care in their preparation, and thoroughness of the work done. Some cover highly technical research work, important in a particular field of electrical progress, while others are of somewhat more general interest. All contribute information of value and it has been a matter of considerable difficulty to determine the prize paper in both of the groups.

"After careful deliberation we have selected the following:

First Paper Prize for the Year 1925

A Two-Speed Salient-Pole Synchronous Motor, by R. W. Wieseman (Published in April 1925)

Honorable Mention is awarded to

Effect of Repeated Voltage Application on Fibrous Insulation, by F. M. Clark (Published in January 1925)

Overvoltages on Transmission Systems Due to Dropping of Load, by E. J. Burnham (Published in June 1925)

"In reviewing the papers coming under the transmission group, it also was extremely difficult owing to the general excellence of the papers offered, to select one which might be considered to surpass the rest. The Committee, however, has agreed on the following:

Transmission Prize

The Klydonograph and Its Application to Surge Investigation, by J. H. Cox and J. W. Legg, (Published in October 1925 issue of the JOURNAL)

Honorable Mention is awarded to

Power System Transients, by V. Bush and R. D. Booth, (Published in March 1925 issue of the JOURNAL)

Fundamental Considerations of Power Limits of Transmission Systems, by R. E. Doherty and H. H. Dewey, (Published in October 1925 issue of the JOURNAL)."

Arrangements were made for the presentation of these prizes at the Annual Convention of the Institute, White Sulphur Springs, West Virginia, on Tuesday morning, June 22.

Revised Report on Standards for Electrical Measuring Instruments Available

A completely revised report on A. I. E. E. Standards for Electrical Measuring Instruments (Section 33 of the Revised Standards) is now available, without charge, for distribution to all those interested in the subject, members or non-members.

This report is issued for purposes of criticism and revision before final adoption as an A. I. E. E. Standards. The Standards Committee will greatly appreciate any suggestions based upon the application of the proposed Standards to general practise. All communications should be addressed to H. E. Farrer, Secretary A. I. E. E. Standards Committee, 33 West 39th St., New York, N. Y.

National Exposition of Power and Mechanical Engineering

Preliminary plans for the Fifth National Exposition of Power and Mechanical Engineering interests indicate that the coming event which is to be held at Grand Central Palace, New York City, December 6-11 inclusive, will be larger and more comprehensive than any of their previous Expositions. Approximately 140 exhibitors have arranged displays in the heating and ventilating field, some 75 in machinery and considerable space will be devoted to exhibits on power generating equipment. In all, the exhibitors will total over 400. Mr. I. E. Moultrop of the Edison Illuminating Co. of Boston is chairman of the Advisory Board and the managers of the Exposition are Charles F. Roth and Fred W. Payne, International Exposition Company, Grand Central Station, to whom all inquiries should be addressed.

New York Electrical Society Develops a Neglected Field

ELECTS OFFICERS FOR 1926-27

At the annual meeting of the New York Electrical Society held on the afternoon of June 14, 1926 at Institute headquarters, 33 West 39th Street, the retiring President of the Society, H. A. Kidder, Superintendent of Motor Power, Interborough Rapid Transit Company, called attention to the much broadened aim and scope of the New York Electrical Society as instanced in its work during the past year. He outlined the new policy, as follows: "To interpret to thinking people the newest things in discovery and science; to present in its meetings the latest achievements in the art and in industry; to acquaint the public with the proper status of teachers, scientific workers and engineers, and with the social value of their work." The determined attempt to shape the work of the Society in the direction indicated has been marked with rapid and increasing success. Attendance at meetings has jumped to an average of approximately 850. Through popularization, the meetings have evidently gained greatly in favor with those within the industry. It is felt that such work as the New York Electrical Society is trying to do, should be done nationally, for if accomplished it would constitute an important and valuable public service. The better people understand the nature of scientific and industrial research and the nature and social value of the work of the engineer, the greater will be the resources at the command of such workers.

The plans for the fall meetings are still tentative. One of particular interest, which is sure to be held, will be a demonstration of "Synchronized Talking Motion Pictures and Music" with popularized explanation of the process of development and operation.

The following officers were elected for the administrative year 1926-27: President, S. P. Grace, Commercial Development Engineer, Bell Telephone Laboratories, Inc.; Vice-Presidents; E. E. Dorting; Lighting Engineer, Interborough Rapid Transit Co.; Dr. E. E. Free, Consulting Engineer, J. P. Alexander, Sales Engineer, General Electric Co.; Treasurer, David Darlington, Assistant Treasurer, New York Edison Co.; Secretary, H. E. Farrer.

Automotive Engineers to Discuss Aircraft Progress

Three technical sessions, an inspection trip to the Naval Aircraft Factory and an Aeronautic Banquet will be the attractions at the annual aeronautic meeting of the Society of Automotive Engineers, to be held in Philadelphia on September 2 and 3 at the Bellevue-Stratford hotel. This meeting immediately precedes the National air races to be run in Philadelphia consecutively from September 4 to 11.

In view of the great amount of night flying that is now being done and that will increase greatly in the future, a joint address on equipment and methods for illumination of air routes, to be presented at the same session by C. T. Ludington, of the B B T Corporation, and H. C. Ritchie, of the General Electric Co., will be of much interest.

Direction finding by radio in an airplane is a recent development of prime importance, particularly when the landscape is obscured by darkness, fog or storms. The remarkable advancement that has been made in the practical application of directional radio to air transport will be described by Lieut. L. M. Wolfe and Capt. W. H. Murphy, of the Air Service radio laboratory at McCook Field, Dayton, O.

National Research Council

Doctor Charles M. Upham Receives New Appointment

The engineering world will be interested in the announcement that Charles M. Upham, who, for five years was North Carolina's Chief Highway Engineer, has tendered his resignation effective June 1st, and will shoulder the duties of Managing Director of the American Road Builders' Association, and in addition, accept a few connections as consulting engineer, among them, the reorganization of the construction division of the Mexican Federal Highway Commission, he already having reorganized the engineering section.

Doctor Upham received two degrees from Tufts College and a third from the North Carolina State University. He is Director of the Highway Research Board of the National Research Council, Vice-President of the National Traffic Association, President of the North Carolina Society of Civil Engineers, Member of Concrete Institute, Permanent International Association, of Road Congresses and other engineering and highway organizations.

The John Ericsson Medal Award

The first award of the John Ericsson gold medal was made to Doctor Svante Arrhenius on the evening of May 29th at the Hotel Willard, Washington, D. C. This was following the unveiling of the memorial Ericsson Statue on the Mall at which the Swedish Crown Prince, Princess Louise, President Coolidge were present, besides many other distinguished international figures.

Graduate Instruction in the Moore School

Beginning with the academic year 1926-27, graduate instruction will be offered in the Moore School of Electrical Engineering, with the degree of Master of Science in Electrical Engineering.

A prescribed course will be offered, the purpose of which is to prepare young men for engineering research or for teaching. The course includes the following subjects: Introduction to Mathematical Physics, Advanced Mathematics for Engineers, Advanced Electric Circuit Theory, Electron Theory and its Engineering Applications, and a Thesis.

To be admitted to this graduate course, the applicant must have completed with credit an undergraduate course in Electrical Engineering substantially equivalent to that given in the Moore School.

In order to encourage students who are properly qualified to add a fifth year to their University training, four graduate fellowships are offered. Each fellowship carries free tuition and a cash stipend of $500, payable in equal installments, October 1 and February 1. Applications for these fellowships should be addressed to the Dean, Moore School of Electrical Engineering, University of Pennsylvania, Philadelphia, Pa.

PERSONAL MENTION

Thos. W. Wootton has resigned from the Adirondack Power and Light Corporation of Schenectady, N. Y., and is now located in the engineering department of the Duquesne Light Company, Pittsburgh, Pa.

R. L. McLellan, managing director of the Cia Westinghouse Electric Internacional, S. A., of Argentine, has recently been elected president of the United States Chamber of Commerce in Argentine.

W. R. Whitney, director of the research laboratory, and E. F. W. Alexanderson, consulting engineer who gained international fame with his radio inventions and developments, were awarded the honorary degree of doctor of science on Monday, June 14, Dr. Whitney at Syracuse University and Mr. Alexanderson at Union College.

Anson W. Burchard, chairman of the board of directors of the International General Electric Company and vice-chairman of the General Electric Company, recently received the degree of doctor of laws from Union College.

W. J. Foster, consulting engineer of the General Electric Company, had the honorary degree of doctor of science conferred upon him by Williams College at its commencement exercises on Monday, June 21. Mr. Foster, an alumnus of Williams College, took graduate work at both Williams and Cornell. With the General Electric Company he has specialized in alternating-current apparatus design.

Homer Clyde Snook, a fellow of the Institute, has just received the degree of Doctor of Science from Ohio Wesleyan University. Doctor Snooks has been referred to as "originator of many fundamental patents in X-ray and wireless inventions; organizer of electrical manufacturing companies; holder of the Edwards Longstreth Medal of the Franklin Institute; staff engineer, Bell Telephone Laboratories, New York; gifted with insight and technical proficiency to have rendered in scientific fields a service of high order."

Obituary

Rudolf Schmolck, who was enrolled as an Associate of the Institute during the year 1925, died May 5, 1926, in Chicago. Mr. Schmolck was born in Germany in 1892, and was educated at the University of Heidelberg and the University of Berlin. Since December 1923 he had been employed by the Automatic Electric Co. of Chicago as a research engineer.

Olin J. Emmons died at his home in Elgin, Illinios, on the 9th of May. For ten years he had been an Associate of the Institute. Mr. Emmons received his electrical education at the University of Iowa, where he took the B. S. degree in 1907 and the E. E. in 1914. At the time of his death he was a wire chief at the Chicago Telephone Co.

Benjamin T. Viall, chief electrician for the Sunnyside Mining and Milling Co. at Eureka, Colorado, died at Silverton, Colorado, Feb. 3, 1926. Mr. Viall was born in 1873, and was graduated from Leland Stanford University in 1900. After three years spent with the General Electric Co. and the Edison Electric Co. he went with the Los Angeles Traction Co. in 1903. The same year he became an Associate of the Institute.

Charles W. Schaifer died in Schenectady, N. Y., on the 4th of April. For eleven years he had been in charge of the section handling "Special Testing of Electrical Machinery and Devices" in the General Engineering Laboratory of the General Electric Co. Mr. Shaifer was a graduate of the Agricultural and Mechanical College of Missippi of the class of 1912, and an Associate of the Institute since 1925.

Charles Griffith Young, Fellow of the Institute, died suddenly in Porto Rico, June 16, while there on a professional engagement. Mr. Young was born at Bath, Steuben County, New York, November 1, 1866. He attended the Haverling Academy there, taking special courses on technical subjects under private tutelage. His first work in the field was with the Schuyler Electric Company, of Hartford and Middletown, Conn., with whom he took an expert course in their every deparment during a two years' period. In 1887 he became general superintendent and electrician for the Mount Morris Electric Light Company, New York City, remaining with them until 1892, when he was chosen construction manager for the White-Crosby Company and the J. G. White Engineering Co., with foreign and domestic practise. Under his direction and operation of public utilities and construction engineering, over 2000 miles of electric railways were built in this and other countries. Mr. Young specialized upon investigations of professional undertakings, both proposed and actual, ultimately leading into the development of his own company, The C. G. Young Co., Inc., of which he was president. His engineering work extended over a wide range,—Canada, South America, Central America, China, Japan, and the Phillippines, New Zealand, Australia, Siberia and several of the European countries. He joined the Institute as an Associate in 1889, but in 1913 was transferred to the grade of Fellow. He was a respected and active member of the National Electric Light Association, the New York Electrical Society, the American Electric Railway Transportation and Traffic Association, the American Electric Railway Engineering Association, Associate Member of the American Society of Civil Engineers, member of the Pan American Society, the Pan American Chamber of Commerce, the Steuben Society, beside belonging to the Engineers' Club, the Railway Club, the Indian House Club and the Circumnavigators. He was the author of a paper of technical worth entitled, "Logical Basis for Valuations." This, besides being reprinted in separate pamphlet form, was published in the *Electric Traction* weekly of Jan. 21, 1911. Mr. Young had been three times around the world.

A. R. Rivet, an Associate of the Institute since 1903, died the 23rd of May in St. Louis, Mo. He was a former editor of the *Electrical Era*, a monthly published in that city, and at the time of his death was financial and commercial editor of the *St. Louis Globe-Democrat*. Mr. Rivet had had much practical electrical experience. He was born at Florissant, Mo., and for over a year was connected with the Municipal Electric Lighting Co. there, having charge of the contracting and estimating of cost of erection of Commerical Arc Lamps. He also was in charge of the motor department of the General Electric Co. in that city for about a year. For several years, he served as expert in the purchase of electrical machinery for isolated plants and was considered a valuable authority by all employing

his services. Mr. Rivet was an inveterate student and in his personal library he had all volums of the *Electrical World* for 15 years back and the *Street Railway Journal* for ten years.

George D. Shepardson, member of the Institute and head of the Electrical Engineering Dept. of the University of Minnesota died at Florence, Italy, of pneumonia, May 26. He left last spring for a trip around the world on a sabbatical leave of absence until next September.

Prof. Shepardson was born November 20, 1864 at Cincinnati Ohio. He attended the Granville Ohio High School and graduated from Denison University 1885 A. B. and A. M. 1888, specializing in Latin, Greek, German and French. He received his degree of Mechanical Engineer from Cornell in 1889. During his other sabbatical year in 1912, he received a degree of Doctor of Science from Harvard. One of his hobbies was the collectiong of old forms of lighting devices. While on his trip he had already gathered a number of primitive and ancient lamps of various designs for the museum of the Electrical Engineering Department of the University. These are now lying in bond in Minneapolis.

Prof. Shepardson has taught at the Young Ladies Institute at Granville, Ohio, Cornell University and since 1891 until his death has been Head of the Department of Electrical Engineering at the University of Minnesota. During the period of his professorship at the University of Minnesota the department has grown from almost nothing to a point where it is the largest in the College of Engineering, graduating 80 senior electrical engineers this spring and now housed in a new building costing $375,000.

Prof. Shepardson was a very prolific writer, having published more than 125 technical articles, in addition to several books, one of the latter "Elements of Electrical Engineering" for now being used in several colleges as a textbook for sophomore electrical engineers.

He was a member of a number of technical societies, among them the Society for the Promotion of Engineering Education, American Association for the Advancement of Science.

John J. Flather, head of the Department of Mechanical Engineering at the University of Minnesota and Associate of the Institute, died suddenly on May 14th at his home in Minneapolis.

Professor Flather was born at Philadelphia, June 9, 1862. He was educated in private schools in Scotland, at the High School in Bridgeport, Conn., and at the Sheffield Scientific School, Yale University, from which he was graduated in 1883. He took graduate studies at Yale, Cornell and the University of Edinburgh, receiving his Ph. B. from Yale in 1885 and his M. M. E. from Cornell in 1890. His early practical experience covered a full machinist's apprenticeship in various New England shops, including Flather & Co., Nashua, N. H.; he served also as foreman at the Ansonia Electric Supply Co. and as superintendent for the Hotchkiss Mfg. Co. In 1888 he became instructor in Mechanical Engineering at Lehigh University, remaining there for three years, followed by seven years at Purdue University. In 1898 he became Professor of Mechanical Engineering at the University of Minnesota, where he remained until the time of his death. He was a prolific writer, and his consulting work covered some import engineering projects of the Northwest, including municipal water works, electric light plants, factories and power plants. He entered the research field in 1888 investigating gas and combustion performances with natural gas, artificial gas, gasoline and kerosene power for machinery drive; also locomotive tests, train resistance tests, rope, belt and gear drive, refrigeration and many other fields of engineering interest. He joined the Institute in 1892 and was also a member of the Society of Industrial Engineers, the American Association of University Professors, the Minneapolis Engineers' Club, the Newcomen Society of London, the Authors' Club and the honorary societies of Sigma Xi, Tau Beta Pi and Pi Tau Sigma. He was secretary and vice-president of Section D of the American Association for the Advancement of Science and served as treasurer and vice-president to the Society for the Promotion of Engineering Education.

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, together with the addresses as they now appear on the Institute records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th St., New York, N. Y.

All members are urged to notify the Institute Headquarters promptly of any change in mailing or business address, thus relieving the member of needless annoyance and also assuring the prompt delivery of Institute mail, the accuracy of our mailing records, and the elimination of unnecessary expense for postage and clerical work.

1.—J. Roy Barclay, 3424 Harrison, Kansas City, Mo.
2.—I. V. Beall, Wright Hotel, 4th & Hinkson Sts., Chester, Pa.
3.—Reynolds Bellows, 28 East 39th St., New York, N. Y.
4.—William A. R. Brown, c/o Radio Corp. of America, 33 West 42nd St., New York, N. Y.
5.—Aleck. Burk, c/o Lempert, 1327 Wilkins Ave., New York N. Y.
6.—J. F. Clinton, 3682 Broadway, New York, N. Y.
7.—A. G. Corbin, 753 Crescent Ave., Buffalo, N. Y.
8.—HughDenehy,The Inst. of Elect, Engrs., Savoy Pl., Victoria Embankment, London W. C. 2, Eng.
9.—John P. Flood, 414 No. Iowa Ave., Eagle Grove, Iowa.
10.—John Fowler, 25 Bettswood Rd., Norwalk, Conn.
11.—Clyde D. Grim, 623 Chestnut St., Reading, Pa.
12.—Frank I. Grover, 1831 E. 82nd St., Terrace, Kansas City, Mo.
13.—Stephan G. Guth, 419 Hampton Ave., Wilkinsburg, Pa.
14.—A. R. Henry, 633 Coristine Bldg., 20 St. Nicholas St., Montreal, Que, Can.
15.—William A. Hincy, Colonial Apts., Media, Pa.
16.—J. W. Hopkins, 136 E. 3rd St., Keyport, N. J.
17.—Niels K. Knudsen, N. Y. Edison Co., 44 E. 23rd St., New York, N. Y.
18.—Alexander Knut, 11th Ave. & 17th St., New York, N. Y.
19.—F. A. Lindlof. 610 So. Spring St., Los Angeles, Calif.
20.—Charles Wm. Lucek, 1454 First Ave., New York, N. Y.
21.—Shu-Sing Man, 541 West 124th St., New York, N. Y.
22.—Irving Menschik, 48 W. 4th St., New York, N. Y.
23.—Arthur R. Michaelson, Mezzine Dv., Cresskill, N. J.
24.—Erwin H. Mitchell, 481 6th St., Brooklyn, N. Y.
25.—Daniel T. Morgan, Power, W. Va.
26.—Jose P. Ortiz, 23rd St. & 4th Ave., New York, N. Y.
27.—Olof E. Permanson, 44 E. 23rd St., New York, N. Y.
28.—J. C. Peterson, 5125 Kimbark Ave., Chicago, Ill.
29.—Chester A. Raymond, 131 W. 17th St., Erie, Pa.
30.—Irving T. Roberts, 2355 Prairie Ave., Evanston, Ill.
31.—Wm. D. Robinson, Sterro-Woolley, Wash.
32.—Carl Russell, Albers Apt. G., Chehalis, Wash.
33.—W. J. Strieby, 104 Broad St., New York, N. Y.
34.—Herbert S. Summers, Standard Oil Co., of N. Y., Sofia, Bulgaria.
35.—O. G. Utt, 4738 Oak St., Kansas City, Mo.
36.—Albert C. Weyandt, 1200½ Negley St., Farrell, Pa.
37.—C. A. Winder, Southern Equipment Co., San Antonio, Tex.
38.—Flavel M. Williams, 106 So. Elliott St., Brooklyn, N. Y.
39.—Fred Willoughby, Jr., 500 West 111th St., New York, N. Y.
40.—W. H. Wilson, 13 Westminster Ave., East Park Hull, England.
41.—W. G. Withington, Commercial Nat'l Bank Bldg., Washington, D. C.

Engineering Societies Library

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Library maintains a collection of modern technical books which may be rented by members residing in North America. A rental of five cents a day, plus transportation, is charged.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 5 p. m.

BOOK NOTICES MAY 1-31, 1926

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statement made; these are taken from the preface or the text of the book.

All books listed may be consulted in the Engineering Societies Library.

Alternating Currents.

By Carl Edward Magnusson. 3rd edition. N. Y., McGraw-Hill Book Co., 1926. 611 pp., illus., diagrs., tables, 9 x 6 in., cloth. $5.00.

A textbook based on the course given in the University of Washington. The aim has been to aid the student to gain clear concepts of what takes place in alternating-current machinery, to explain the relations between the factors involved and to explain the physical facts in mathematical forms in such a manner that the student shall understand the equations and be able to use them in the solution of industrial problems. The new edition has been thoroughly revised.

Aus Dem Reich der Technik.

By Max Maria von Weber. Berlin, V. D. I. Verlag, 1926. 188 pp., port., 8 x 6 in., cloth. 7,-r. m.

This collection of stories, long out of print, is now reissued by the press of the Verein deutscher Ingenieure. Weber was born in 1822 and died in 1881. He was educated as an engineer and spent his life in railroad service in Germany and Austria. He is best known, however, for his stories, which unite technical knowledge and poetic ability in an unusual degree. Those here reproduced are based on various incidents of railroad operation. Through them all runs a desire to arouse pride in his vocation in the railroad employer and to show the public the importance to national prosperity of the engineer and the mechanic.

Aussendung und Empfang Elektrischer Wellen.

By Reinhold Rüdenberg. Berlin, Julius Springer, 1926. 67 pp., diagrs., 9 x 6 in., paper. 3,90 r. m.

There are many books on the action of radio sending and receiving mechanisms, but there is not a great deal available on the mechanism of the wave passage from sender to receiver. In this little book the interaction between the currents and voltages in the stations and the electromagnetic waves flowing between them is considered, together with the problem of wave propagation in the intervening medium. The discussion is confined to undamped waves.

Corrosion; Causes and Prevention.

By Frank N. Speller. N. Y., McGraw-Hill Book Co., 1926. 621 pp., illus., diagrs., tables, 9 x 6 in., cloth. $6.00.

An important reference work for all who are interested in any of the many phases of the problem of corrosion, combined with a handbook of practical preventive methods of interest to engineers and architects.

Part one treats of general principles. After an explanation of the nature and mechanism of corrosion and of the theories advanced to explain it, the author discusses the influence of methods of manufacture and treatment, of composition and of external factors on corrosion. The principles and methods of testing are then described and a chapter is devoted to the question of the relative corrodability of the various ferrous metals.

Part two discusses measure for preventing corrosion under various service conditions. Corrosion in the air, under water or under ground, corrosion in hot water systems and in steam plants and corrosion caused by chemicals or electric currents are discussed at length. Many references to other work are given in the notes and bibliography.

Dr. Speller's long study of the subject has enabled him to write a book of great value to all engineers.

Die Drahtseilbahnen.

By P. Stephan. 4th edition. Berlin, Julius Springer, 1926. 572 pp., illus., plates, 9 x 6 in., cloth. 33,-m. k.

A detailed descriptive work on aerial ropeways and cableways, and telphers. The book is written from the point of view of the user rather than the manufacturer.

After a brief historical introduction, the various elements of ropeways (cables, supports, cars, stations, safety devices, etc.) are described. Examples of the use of ropeways as mountain railways and industrial conveyors, in mines, harbors and mills are then given, after which special types, such as gravity ropeways, single-cable ways, passenger ropeways and cableways are discussed. Economic and legal matters are then taken up, followed by a chapter on erection and operation. The types described are those now manufactured in Germany.

Ethics of Business.

By Edgar L. Heermance. N. Y., Harper & Bros., 1926. 244 pp., 8 x 6 in., cloth. $2.00.

Standards of business conduct, sometimes unwritten, sometimes expressed in definite codes, have been developing during the past quarter-century until today, Mr. Heermance believes, the average American merchant of the better class is probably more ethical than his patrons. In this book he presents these standards and the reasons for them, giving a useful picture of the development of business ethics in the United States. The author also intends his book as an introduction to social ethics, and therefore makes certain generalizations and interpretations of the ethical process in trade associations, as a contribution to ethical theory.

Industrial Stoichiometry.

By Warren K. Lewis and Arthur H. Radasch. N. Y., McGraw-Hill Book Co., 1926. (Chemical Engineering Series). 174 pp., diagrs., tables, 9 x 6 in., cloth. $2.50.

While the chemist is always taught the use of stoichiometric methods of computing quantitative analyses, he frequently is not trained to use them in industrial work. This textbook is designed to familiarize the beginner with correct methods for the quantitative interpretation of data in industrial work by a detailed presentation of typical cases of industrial processes, such as the operation of gas producers, lime burning, kiln and furnace design, plant design, sulfur burning, and iron smelting.

Insulated Electric Cables, v. 1; Materials and Design.

By C. J. Beaver. N. Y., D. Van Nostrand, 1926. 264 pp., illus., diagrs., tables, 10 x 7 in., cloth. $11.00.

Intended to supplement recent publications about insulated cables, which are chiefly devoted to their electrical properties, by a statement of the principles that underlie their design and manufacture. These, the author says, have not been comprehensively treated in any previous work.

The present half of the work discusses the materials—metals, insulants and protective substances—, the design of conductors,

the design and properties of dielectrics, and the factors in voltage rating. The second volume will treat of manufacture and installation.

Jahrbuch der Elektrotechnik . . . . 1924.

Edited by Karl Strecker. Mün. u. Ber., R. Oldenbourg, 1926. 269 pp., 10 x 7 in., paper. 14,20 mk.; bound, 15,40 mk.

A digest of over five thousand articles on electrical engineering which were published in some two hundred periodicals during 1924. The digests are the work of specialists and give a valuable summary of advances in each line, conveniently arranged for reference use. Machine design, power transmission and distribution, power plants, lighting, railroads, electric driving and other industrial uses of electricity, primary and secondary batteries, electrochemistry and electrometallurgy, telegraphy, telephony, signaling, electrical measurements and scientific investigations are included in the book. References are given to the original papers and author and subject indexes are supplied.

New View of Surface Forces; A Collection of the Scientific Papers of Wilson Taylor. Toronto, Univ. of Toronto Press, 1925. 240 pp., illus., diagrs., tables, 9 x 6 in., cloth. A Memorial Volume. Price not quoted.

When the author died, in 1923, after four years of research in physics, he left a number of papers, chiefly upon surface tension and molecular physics. Those here printed discuss the coalescence of liquid spheres and the law governing it, cohesion and adhesion in liquids and solids, the potential energy of free molecules, etc. One paper is devoted to flotation oils and their mode of action.

De Ontwikkeling van de Electriciteitsvoorziening van Nederland. 1925.

By Vereeniging van Directeuren van Electriciteitsbedrijven in Nederland. Amsterdam, P. N. Van Kampen & Zoon, 1926. 568 pp., illus., maps, 11 x 9 in., cloth. 25 guilders. (This volume can be supplied by the Central Bureau of the Association, Maastricht, Breedestraat 11, at the price quoted).

In commemoration of its tenth anniversary, the Association of Managers of Electricity Supply Works in the Netherlands has issued this handsome volume. It contains elaborately illustrated accounts of the service provided by the utilities controlled by members of the Association, which furnish practically the entire electrical supply of the country. In addition to descriptions of equipment, service, etc., detailed statistics and maps are included, so that the book is a complete presentation of the development of electricity supply in the Netherlands.

Railway Engineering and Maintenance Cyclopedia. 2nd edition, 1926, [of Maintenance of Way Cyclopedia]. N. Y., Simmons-Boardman Publ. Co., 1926. 1072 pp., illus., 12 x 9 in., cloth. $8.00.

The Cyclopedia is a convenient, authoritative assemblage of information on current practise in the engineering and maintenance of railroad track, bridges, buildings, water service and signals. This information is arranged in sections, each of which discusses the work of one of these branches. A general section cares for matters of interest to all. A dictionary of terms gives convenient definitions and serves as an index. Condensed catalogs of manufacturers are included. The sections were edited by a number of specialists actively engaged in railroading.

S. A. E. Handbook, March 1926. N. Y., Society of Automotive Engineers, 1926. Various paging, diagrs., tables, 7 x 4 in., fabrikoid. $2.50 to members. $5.00 to non-members.

The standards and recommended practises of the Society of Automotive Engineers, some six hundred in number, have been revised and published in a bound volume of convenient pocket size, replacing the former data sheets supplied to its members. The contents are divided into sections relating to the power, plant, lighting, electrical equipment, parts and fittings, materials, transmission, axles and wheels, tires, frames, etc. Revisions are to appear twice each year hereafter.

Technisches Worterbuch . . . des Maschinen-und Schiffbaues, v. 2; Englisch-Deutsch.

By Erich Krebs. 2nd edition. Ber. u. Lpz., Walter de Gruyter & Co., 1926. 163 pp., 6 x 4 in., cloth. 1,50 r. m.

A convenient English-German pocket dictionary of technical terms used in mechanical engineering and naval architecture. Apparently includes all the principal terms, with satisfactory equivalents, and is remarkably cheap.

La Telephone Automatique.

By H. Milon. Paris, Gauthier-Villars et cie, 1926. 414 pp., illus., plates, 10 x 7 in., paper. 90 fr.

A concise textbook on automatic telephony, prepared especially for French students. The author omits any history of the development of the apparatus and confines himself, after giving an outline of the essential characteristics of the different systems, to a detailed account only of those in use in France. These include the Automatic Electric, the Thomson-Houston, the Siemens and Halske, the Western Electric and several semiautomatic systems. Data for the design of installations are given.

Theory and Practise of Alternating Currents.

By A. T. Dover. Lond. & N. Y., Isaac Pitman & Sons, 1926. 539 pp., illus., diagrs., 9 x 6 in., cloth. $5.00.

Devoted to general principles, circuits, polyphase systems, non-sinusoidal wave-forms, the magnetization of iron, instruments, measurements, and an elementary treatment of the initial conditions in the simpler electric circuits. Intended for use as a college text, introductory to the study of alternating-current machines and apparatus, it treats these principles on a broader basis than some textbooks do. Among the special features are an extended application of the circle diagram to series, parallel series-parallel circuits; the reduction of the general circuit to its equivalent series-parallel form and the development of a load diagram therefor; the calculation of currents in unbalanced polyphase circuits; and the theory of the principal types of measuring instruments.

Past Section and Branch Meetings

SECTION MEETINGS

Atlanta

Developments of the Columbus Electric and Power Company, by R. M. Harding. November 6. Attendance 60.

The Traffic Problem in Atlanta, by P. S. Arkwright, Georgia Railway and Power Co. January 18. Attendance 10.

Recent Developments in the Manufacture of Chemical Fiber, by F. H. Griffith, The Viscose Co., and

Cellucose, by R. C. Dort, the American Cellucose and Chemical Co. March 18. Attendance 27.

Ceramics, by A. V. Henry, Georgia School of Technology. April 22. Attendance 17.

Baltimore

Radio Broadcasting Station, Consolidated Gas and Electric Company, by F. A. Fallon, and

Radio Equipment, by P. M. Rainey, Graybar Electric Co. January 15. Attendance 65.

Mercury-Arc Rectifier as Applied to Power Development, by H. D. Brown, General Electric Co. Illustrated with slides. February 19. Attendance 90.

Mechanical Power and Trend of Civilization, by C. E. Skinner, Westinghouse Electric and Mfg. Co. March 19. Attendance 110.

Automatic Testing of Watt Hour Meters, by J. S. Cruickshank, Consolidated Gas, Electric Light and Power Co., and

Maintenance and Care of Storage Batteries, by A. Albaugh and F. Fried, Consolidated Gas, Electric Light and Power Co. April 16. Attendance 87.

Annual Banquet. Joint with A. S. M. E. April 29. Attendance 156.

Boston

Business Meeting. Election of Officers. Banquet preceded the meeting. May 18. Attendance 238.

Cincinnati

Research, by Dean Herman Schneider, University of Cincinnati. Illustrated with slides. May 20. Attendance 216.

Cleveland

Mental Attitude, by Dr. M. I. Pupin,, National President, A. I. E. E. May 18. Attendance 100.

Connecticut

Fatigue Prevention is Accident Prevention, by Dr. H. W. Haggard, Yale University. The following officers were elected: Chairman: A. E. Knowlton; Secretary-Treasurer, R. G. Warner. May 19. Attendance 40.

Denver

The Changing Status of the Engineer, by Dr. F. B. Jewett, American Telephone and Telegraph Co. The following officers were elected: Chairman, W. H. Edmunds; Vice-Chairman, A. L. Jones; Secretary-Treasurer, R. B. Bonney. May 28. Attendance 500.

Erie

Talk by Giuseppe Faccioli, General Electric Co., on a trip through Europe in a machine, with special reference to engineering conditions. The following officers were elected: Chairman, F. A. Tennant; Secretary, L. H. Curtis. May 25. Attendance 94.

Ithaca

The Social and Economic Aspects of Niagara Falls, by W. K. Bradbury, Niagara Falls Power Co. Illustrated with slides and motion pictures. A dinner preceded the meeting. May 7. Attendance 125.

Lehigh Valley

Oil Switches, by Wm. S. Edsall, Condit Electric Mfg. Co., and

Application of the Electric Motor to Steel Mills, by G. E. Stoltz, Westinghouse Electric and Mfg. Co. A dinner preceded the meeting. April 23. Attendance 135.

Lynn

Street and Highway Safety, addresses by Dr. George W. Haywood, President of Lynn City Council; Hon. Ralph S. Bauer, Mayor of Lynn; Deputy-Commissioner Good of Boston; C. A. B. Halvorson, General Electric Company, and S. C. Rogers, Street-Lighting Department, Lynn. June 3. Attendance 150.

Madison

A talk was given by D. W. Mead, University of Wisconsin, on some of his experiences in building hydro-electric plants. The following officers were elected: Chairman, E. J. Kallevang; Secretary, H. J. Hunt. May 26. Attendance 24.

Milwaukee

The Inadequacy of American Patent and Trade-Mark Protection, by R. S. Hoar, The Bucyrus Co. May 19. Attendance 100.

Minnesota

Dinner Dance. May 11. Attendance 61.

Nebraska

Long Distance Telephone Transmission—Fifty Years of Progress, by A. F. Rose, American Telephone and Telegraph Co. Demonstrated. May 12. Attendance 85.

Pittsfield

Street and Highway Safety—addresses by W. A. Whittlesey, engineer of the Pittsfield Electric Co., and Chief of Police John L. Sullivan. May 27. Attendance 150.

Portland

Manual, Supervisory and Automatic Control, by Albert Kalin, Westinghouse Electric and Mfg. Co. A motion picture, entitled "From Mine to Consumer," was shown. May 12. Attendance 85.

Rochester

A motion picture, entitled "The Yoke of the Past," was shown. The following officers were elected: Chairman, E. C. Karker; Vice-Chairman, R. G. Thompson; Secretary-Treasurer, J. R. Clark. May 7. Attendance 40.

San Francisco

Elements of Transmission-Line Stability Problems, by A. W. Copley, Westinghouse Elec. & Mfg. Co., and Roy Wilkins, Pacific Gas and Elec. Co. A dinner preceded the meeting. May 28. Attendance 80.

Supervisory Systems for Control and Indication, by C. E. Stewart. Illustrated with motion pictures and slides. June 3. Attendance 58.

Sharon

Mechanical Power and the Trend of Civilization, by C. E. Skinner, Westinghouse Electric and Mfg. Co. The following officers were elected: Chairman, H. L. Cole; Secretary-Treasurer, L. H. Hill. June 1. Attendance 75.

Springfield

Electric Time Equipment, by G. F. Harter, The Standard Electric Time Co. May 24. Attendance 45.

Syracuse

Radio and Interference, by E. P. Peck, Utica Gas and Electric Co. March 8. Attendance 175.

Developments in Radio Wave Propagation, by E. F. W. Alexanderson, Radio Corporation of America. March 29. Attendance 225.

Engineering Mechanics at the Bureau of Standards, by L. B. Tuckerman. April 12. Attendance 195.

Toledo

Inspection trip to the Toledo Furnace Company. May 19. Attendance 32.

Urbana

Business Meeting. The following officers were elected: Chairman, J. T. Tykociner; Secretary-Treasurer, L. B. Archer. May 12. Attendance 12.

Utah

New Electrical Developments, by A. L. Jones, General Electric Co. Illustrated with slides. May 26. Attendance 40.

Vancouver

Annual Meeting. The following officers were elected: Chairman, R. L. Hall; Secretary, C. W. Colvin. June 1. Attendance 46.

BRANCH MEETINGS

Alabama Polytechnic Institute

The Oscillograph, by Prof. J. A. Douglas. Mr. W. B. Fish also gave a demonstration of a Dudell-type machine. May 12. Attendance 14.

University of Arizona

Business Meeting. April 17. Attendance 11.

The Orthophonic Reproduction of Sound, by Dr. Earl Warner. Motion pictures, entitled "Electric Transmission of Speech," and "The Single Ridge Method," were shown. April 24. Attendance 24.

Rectification of Alternating Current, by R. O. Wright;

Textile Engineering, by W. R. Brownlee, and

Commercial Phases of the Telephone, by W. T. Voss. May 1. Attendance 12.

Business Meeting. May 8. Attendance 12.

Super-Power Systems, by Geo. Diamos. May 15. Attendance 20.

A motion picture, entitled "The Audion," was shown. The following officers were elected: President, J. W. Cruse; Vice-President, T. E. Davis. May 22. Attendance 20.

University of Arkansas

Illinois Central Switching Yard, by F. H. Smith, and

Frog-Leg Windings, by Fred Ross. June 1. Attendance 9.

Brooklyn Polytechnic Institute

Vacuum-Tube Crest Voltmeters, by Paul Heise, student;

Induction Motors, by Wallace Griesman, student. Mr. Fred Siemers gave a demonstration with a Tesla coil giving a 30-inch spark. The following officers were elected: President, Ferdinand Wankel; Vice-President, William Dalton; Treasurer, Fred Wahlers; Secretary, Joseph Heller. May 21. Attendance 38.

Bucknell University

Business Meeting. The following officers were elected: President, A. Fogelsanger; Vice-President, G. Timm; Secretary-Treasurer, J. D. Johnson. May 17. Attendance 38.

California Institute of Technology

Motion pictures, entitled "King of the Rails" and "The Potter's Wheel," were shown. May 17. Attendance 46.

The Operation of a Large Power Company, by H. A. Barre, Southern California Edison Co. The following officers were elected: Chairman, Thomas Gottier; Vice-Chairman, Don Hinkston; Secretary, Alan Capon; Treasurer, Carter Blankenberg. May 28. Attendance 24.

Carnegie Institute of Technology

The Uses of Aluminum in the Electrical Industry, by Theodore Varney, Aluminum Company of America. April 28. Attendance 35.

Banquet. The following officers were elected: Chairman, J. R. Power; Vice-Chairman, W. F. Simpson; Secretary, R. O. Perrine, Treasurer, J. T. Chidester. May 18. Attendance 55.

University of Colorado

A motion picture, entitled "The Single Ridge," was shown. May 12. Attendance 25.

Business Meeting. The following officers were elected: President, A. D. Thomas; Vice-President, W. G. Edwards, Jr.; Secretary, J. A. Setter; Treasurer, R. W. Gutshall. June 2. Attendance 22.

University of Denver

Business Meeting. The following officers were elected: Chairman, Harold Henson; Vice-Chairman, Carlyle Connor; Secretary-Treasurer, Allea Ohlson. May 13. Attendance 18.

Drexel Institute

Electrical Show. May 7 and 8. Attendance over 2000.

Business Meeting. The following officers were elected: Chairman, H. D. Baker; Vice-Chairman, G. V. Craddock; Secretary, J. E. Eininger; Treasurer, T. J. Ballantyne. May 19. Attendance 23.

University of Idaho

Business Meeting. The following officers were elected: President, J. W. Gartin; Vice-President, Cecil Balkow; Secretary-Treasurer, S. Blore. May 25. Attendance 32.

State University of Iowa

Evacuating Electric Lamps, by Nathan Whiting, and

The American Institute of Electrical Engineers and Its Purposes, by Prof. A. H. Ford. May 12. Attendance 37.

Automatic Train-Control Devices, by LeRoy Wyant, Rock Island Railroad, Mr. Lyon, Ragan Automatic Train Control Device Co., and E. Wanamaker, Rock Island Railroad. May 21. Attendance 37.

Business Meeting. May 26. Attendance 33.

Kansas State College

Electrical Power Applications in the Printing Industry, by Mr. Higgenbottom. The following officers were elected: President, A. M. Young; Vice-President, K. B. Mudge; Recording Secretary, L. S. Hobson; Corresponding Secretary, John Yost; Treasurer, C. C. Tate. May 10. Attendance 66.

University of Kansas

Business Meeting. The following officers were elected: President, W. L. Immer; Vice-President, R. M. Alspaugh; Secretary, H. R. Hilkey; Treasurer, Glen Kireckhaus. May 13. Attendance 40.

Michigan State College

Business Meeting. June 3. Attendance 18.

University of Michigan

Business Meeting. The following officers were elected: Chairman, M. H. Nelson; Vice-Chairman, R. R. Swain; Secretary, H. R. Stevenson; Treasurer, W. I. Poch. May 26. Attendance 19.

Engineering School of Milwaukee

Inspection trip to the Westinghouse Lamp Works. May 21. Attendance 44.

Automobile Headlight Illumination, by E. J. Lehnen. A motion picture, entitled "Telephone Inventors of Today," was shown. June 8. Attendance 24.

University of Minnesota

The Development of the Steam Turbine, by C. C. Douglas, General Electric Co. Illustrated with slides. May 12. Attendance 70.

Montana State College

Business Meeting. The following officers were elected: Chairman, W. E. Pakala; Vice-Chairman, Wayne Kobbe. May 13. Attendance 147.

College of the City of New York

Porcelain Insulators, by Mr. Hirsch. Illustrated with slides. May 20. Attendance 14.

Production Methods in the General Electric Company, by W. W. Hambly. June 3. Attendance 26.

Business Meeting. The following officers were elected: Faculty Chairman, Professor H. Baum; Student Chairman, Harold Wolf; Vice-Chairman, Harry Hirsch; Secretary, Joseph Leipziger; Treasurer, E. F. Day. June 10. Attendance 19.

New York University

Business Meeting. The following officers were elected: Chairman, H. U. Hefty; Secretary, Henry Och. May 6. Attendance 20.

University of North Carolina

Short talks were given by the following students: Messrs. Wilson, Smith, Coe, Farmer, Ryan, Cantwell and Mason. May 6. Attendance 38.

Banquet. The following officers were elected: President, H. L. Coe; Vice-President, G. M. Wilson; Secretary, C. M. Lear; Treasurer, J. L. Cantwell. May 20. Attendance 46.

Ohio University

A New Method of Measuring Sound Intensity, by D. B. Green. Illustrated. May 13. Attendance 27.

Oklahoma Agricultural and Mechanical College

Banquet. May 20. Attendance 30.

University of Oklahoma

Business Meeting. The following officers were elected: President, G. B. Brady; Vice-President, Ralph Tyler; Secretary, J. C. Glaze. May 19. Attendance 16.

Oregon State Agricultural College

The Transmission of Pictures by Wire, by A. K. Morehouse, Pacific Telephone and Telegraph Co. Illustrated with slides. May 11. Attendance 55.

Business Meeting. May 28. Attendance 31.

Pennsylvania State College

The Transmission of Pictures by Wire, by J. W. Horton, Bell Laboratories, Inc. Illustrated with slides. May 12. Attendance 50.

Business Meeting. May 26. Attendance 20.

Banquet. June 3. Attendance 78.

University of Pennsylvania

Spring Dance. May 7. Attendance 100.

Business Meeting. The following officers were elected: Chairman, F. H. Riordan, Jr.; Vice-Chairman, W. L. Carns; Treasurer, J. T. Naughton, Jr.; Secretary, Wm. H. Hamilton. May 19.

Social Meeting. May 23. Attendance 150.

Purdue University

Public Utilities, by Stanley Green, Indiana Central Power Co. May 18. Attendance 30.

South Dakota State School of Mines

Business Meeting. The following officers were elected: Chairman, C. Allen; Secretary-Treasurer, Harold Eade. May 24. Attendance 10.

University of South Dakota

Developments of Electrical Machinery in 1925, by Louis Stverak, and

A Modern 220-Kv. Power Transmission Line, by Richard Brackett. January 5. Attendance 9.

Latest Developments in Electrical Instruments, by Will Doohen. Illustrated with slides. The following motion pictures were shown: "The Glow of the Lamp," and "White Coal." February 13. Attendance 72.

Transmission Lines in South Dakota, Mr. G. W. Day. March 9. Attendance 7.

Rearranging the Dynamo Room, by Will Doohen and Louis Stverak. April 12. Attendance 8.

A Piezo-Electric Oscillator Working at 3000 kc. and 4000 kc. per Second, by Richard Brackett. May 11. Attendance 14.

Stanford University

Business Meeting. May 26. Attendance 15.

Business Meeting. June 2. Attendance 12.

Business Meeting. The following officers were elected: Chairman, A. V. Pering; Vice-Chairman, R. H. Brandt; Secretary, J. G. Sharp. June 8. Attendance 17.

Syracuse University

A motion picture, entitled "Temperature and Motor Endurance," was shown. May 3. Attendance 18.

Water Power in New York State, by V. R. Kimball. May 24. Attendance 18.

University of Tennessee

Illustrated lecture by Mr. Nelson, General Electric Co. April 15. Attendance 35.

Business Meeting. The following officers were elected: President, F. N. Green; Vice-President, J. R. McConkey; Secretary-Treasurer, B. M. Gallaher. May 6. Attendance 20.

University of Texas

Business Meeting. The following officers were elected: President, F. W. Langner; Vice-President, R. F. Calhoun; Secretary-Treasurer, F. B. Menger; Corresponding Secretary, H. W. Zuch. May 13. Attendance 10.

Virginia Military Institute

Business Meeting. The following officers were elected: Chairman, R. P. Williamson; Secretary, M. L. Waring. May 25. Attendance 28.

University of Virginia

Hydro-Electric Possibilities Along the St. Lawrence River, by T. M. Linville;

Recent Developments of Moore Gaseous-Conductor Lamps, by H. M. Dixon, Jr., and

Recent Developments in the Reproduction of Music, by J. S. Miller. Motion pictures, entitled "The Telephone, A Modern Marvel," "The Land of the White Cedar," and "Story of a Telephone Conversation," were shown. May 19. Attendance 52.

Business Meeting. The following officers were elected: Chairman, R. C. Small; Secretary, G. L. Lefevre; Treasurer, J. Bronaugh. May 28. Attendance 10.

State College of Washington

Business Meeting. The following officers were elected: President, S. H. White; Vice-President, S. A. Bobe; Secretary, H. R. Meahl; Treasurer, Walter Beattie. June 1. Attendance 20.

Washington University

Business Meeting. The following officers were elected: President, E. B. Kempster, Jr.; Vice-President, Y. O. Waller; Secretary-Treasurer, George Simpson. May 21. Attendance 22.

University of Washington

The Superpower System, by Mr. Hutton, Pacific Coast Engineering Co. Annual Dinner. The following officers were elected: President, C. M. Murray, Jr.; Secretary-Treasurer, R. H. Crosby. June 2. Attendance 29.

West Virginia University

Inspection Trips at Carnegie Tech., by R. W. Beardslee; *Inspection Trips under Auspices of Westinghouse Elec. & Mfg. Co.*, by J. U. Neill; *The Springdale Power Plant*, by M. W. Naylor; *The Colfax Power Plant*, by E. A. Berry; *The Manufacture of Steel Shapes*, by D. S. Roush; *Interesting Things Seen at the Westinghouse Works*, by R. L. Cole; *Machine-Switching Telephone Exchange*, by R. A. Osborne; and *Submarine Indicators*, by I. L. Smith. May 21. Attendance 28.

University of Wisconsin

Hydro-Electric Construction, by Professor Meade. Banquet. May 26. Attendance 60.

Worcester Polytechnic Institute

Business Meeting. The following officers were elected: Chairman, D. A. Calder; Vice-Chairman, R. A. Beth; Treasurer, A. M. Tarbox; Secretary, C. H. Kauke. May 6. Attendance 16.

University of Wyoming

Business Meeting. The following officers were elected: President, John Hicks; Vice-President, William Buchholz; Secretary-Treasurer, James O. Yates. May 19. Attendance 10.

Engineering Societies Employment Service

Under joint management of the national societies of Civil, Mining, Mechanical and Electrical Engineers cooperating with the Western Society of Engineers. The service is available only to their membership, and is maintained as a cooperative bureau by contributions from the societies and their individual members who are directly benefited.

Offices:—33 West 39th St., New York, N. Y.,—W. V. Brown, Manager.

53 West Jackson Blv'de., Room 1736, Chicago, Ill., A. K. Krauser, Manager.

57 Post St., San Francisco, Calif., N. D. Cook, Manager.

MEN AVAILABLE.—Brief announcements will be published without charge but will not be repeated except upon requests received after an interval of one month. Names and records will remain in the active files of the bureau for a period of three months and are renewable upon request. Notices for this Department should be addressed to ***EMPLOYMENT SERVICE, 33 West 39th Street, New York City,*** *and should be received prior to the 15th of the month.*

OPPORTUNITIES.—A Bulletin of engineering positions available is published weekly and is available to members of the Societies concerned at a subscription rate of $3 per quarter, or $10 per annum, payable in advance. Positions not filled promptly as a result of publication in the Bulletin may be announced herein, as formerly.

VOLUNTARY CONTRIBUTIONS.—Members obtaining positions through the medium of this service are invited to cooperate with the Societies in the financing of the work by nominal contributions made within thirty days after placement, on the basis of $10 for all positions paying a salary of $2000 or less per annum; $10 plus one per cent of all amounts in excess of $2000 per annum; temporary positions (of one month or less) three per cent of total salary received. The income contributed by the members, together with the finances appropriated by the four societies named above, will it is hoped, be sufficient not only to maintain, but to increase and extend the service.

REPLIES TO ANNOUNCEMENTS.—Replies to announcements published herein or in the Bulletin, should be addressed to the key number indicated in each case, with a two cent stamp attached for reforwarding, and forwarded to the Employment Service as above. Replies received by the bureau after the positions to which they refer have been filled will not be forwarded.

POSITIONS OPEN

PUBLIC UTILITY EXECUTIVE, thoroughly seasoned for general management. X-73.

EXPERIENCED TRANSFORMER ENGINEER, familiar with design and practise relating to high-tension potential transformers and high-tension small distribution and special purpose transformers. Must be capable of original work, both theory and practise. Positions with a new division of an old line manufacturing company, not previously engaged in the manufacture of high-tension electrical apparatus. Location, Connecticut. R-9452.

DISTRICT SUPERINTENDENT, to take charge of the distribution and commercial work in a fast growing and progressive town of eighty thousand. Should be technically trained, experienced with overhead city distribution problems, customers' relations, rate interpretation, motor applications and illumination. Good working knowledge of Spanish essential. Climate healthful. Apply by letter with full particulars regarding past experience, salary, when available, references and enclose recent photograph. Location, Porto Rico. R-9898-C.

MANUFACTURING ELECTRICAL ENGINEER, who can design and plan the production of a complete line of electric stoves. Only engineer who has had practical experience producing electrical stoves will be considered. Apply by letter. Location, West. R-9839-C-R-226-S.

STEAM PLANT BETTERMENT AND SERVICE ENGINEER, with five-ten years' public utility operating experience, principally in steam electric generation. Work is in connection with plant betterment and service division of large public utility management organization. Essential that applicant be fully informed as to operation, maintenance and design of up-to-date

high-pressure steam electric stations and capable of analyzing operating results and costs, as well as rendering all kinds of service in connection with the operation of the steam and utility plants. Some traveling. Apply by letter stating salary expected, when available, and full statement of education, age, and past experience. Headquarters, New York. X-49.

STEAM PLANT BETTERMENT ENGINEER, for steam plant betterment division of large utility management company. Must have at least five years' operating experience in public utility plants. Knowledge of Spanish desirable, not essential. Underfeed stoker experience required. Apply by letter stating age, salary expected, education, when available, and full description of past experience. Headquarters, New York; location, foreign. X-50.

MEN AVAILABLE

EXECUTIVE, graduate electrical engineer, age 32, married, desires permanent position with manufacturing organization where actual selling, purchasing and manufacturing control experience can be used to advantage. Experienced in shop practise and management with knowledge of factory cost and accounting systems. Skilled in production methods, waste elimination, bonus systems and rate setting. A-4070.

GRADUATE ELECTRICAL ENGINEER, 30, married, several years practical and business, some educational experience, desires teaching position offering opportunity for research and advanced study. Excellent scholastic record, naturally adapted to educational work. Can handle electrical or power plant engineering or mathematical subjects. Westinghouse shop course and sales experience. Excellent references. C-1071.

ELECTRICAL ENGINEER, 28, B. S. in E. E., desires teaching position in electrical engineering department of university or college of standing. Desires position with prospects of advancement. Five years' experience in design, estimation and installation of electrical and mechanical equipment. Present position instructor in electrical engineering in well known Western college. Available September. B-9894.

ELECTRICAL ENGINEER, 28, single, desires position with manufacturer electrical apparatus. Five years' experience with large manufacturer electric control apparatus. Some sales experience. B-6274.

ELECTRICAL ENGINEER, graduate Lond., Eng., two years' Canadian hydro experience, five years plant maintenance. At present located Quebec, desires to improve position in Canada. Thorough practical and theoretical experience. Available in one week. At present employed. C-1419.

GRADUATE OF DREXEL INSTITUTE IN ELECTRICAL ENGINEERING, 23, five years general wiring, one year power plant construction, six months underground transmission and distribution work, including test on 13200 volt Conduit Oil Switches. De ires position electrical engineering work. Location, immaterial. C-1477.

ELECTRICAL ENGINEER, 30, married, experienced in the electrical design of power plants, substations, transmission lines, special studies, investigations, reports, etc. Technical graduate, business training. Will consider a connection with a consulting organization or an operating company. C-995-507.

ELECTRICAL AND CIVIL ENGINEER, 35, with fifteen years' experience in electrical and hydro-electric developments. Theoretical training well seasoned with actual experience in all stages from preliminary reports to construction and operation. Executive accustomed to assuming responsibility and delivering results. Fluent Spanish. B-1173.

ELECTRICAL ENGINEER, 30, married, graduate E. E., M. E., seven years' varied experience on central and substation estimating, design, construction and installation, also safety and research work. Five years in responsible positions with private corporation and public utilities. Good record and references. Desires responsible position requiring ingenuity and good judgment with industrial, engineering or small power company, preferably New York or neighboring state. Available on reasonable notice. B-5505.

RECENT COLLEGE GRADUATE, E. E., desires position as instructor in electrical engineering, preferably in New York City. C-1514.

ELECTRICAL SALES ENGINEER, wishes to represent manufacturers of electrical power and control equipment, also special illuminating equipment for industrial use. Location, St. Louis. C-1479.

ASSISTANT ENGINEER, 25, single, B. S. in E. E., two years on Westinghouse test. Desires work with public utility. Location, East, Virginia or North Carolina. C-1314.

ELECTRICAL ENGINEER, college and technical graduate, twenty-five years' broad experience in power plant and substation design, H. T. bus construction, power and light distribution, underground and line transmission, quantity surveys, specification writing, executive correspondence, and office charge, desires position with reliable utility company. Atlantic Coast preferred. B-3231.

ELECTRICAL ENGINEER, 35, married, M. I. T. education, fourteen years' experience, office and field, electrical design of power stations, substations, industrial buildings, desires position with a substantial organization where the experience stated herein can be used to the advantage of employer and employee. Familiar with appraisal work. Holds New York State Professional Engineer's license. Salary $4200. Location, New York City. B-5393.

GRADUATE ELECTRICAL AND MECHANICAL ENGINEER, desires permanent position engineering work Pacific Coast. Two years drafting, designing with electrical manufacturing company, two years substation design, rate engineering large public utility. Good character, pleasing personality, efficient worker. Several languages, European university graduate, 27, married. Minimum salary $175 a month. Present employed. Available month's notice. C-1109.

DISTRIBUTION ENGINEER, technical graduate, married, 33, five years' experience substations, steam and electric power stations, five years' experience in electrical distribution with large public utility in East. Desires location in East. Available one month. B-1410.

POWER SALES ENGINEER. Young man with ability, 34, married, desires connection with public utility who needs a real salesman for new business or contract department. Has had ten years' engineering and selling experience. Technically educated. Salary and expenses. Available August 1st. A-1330.

SUPERINTENDENT ELECTRICAL AND MECHANICAL CONSTRUCTION AND OPERATION-EXECUTIVE, 48, married, technical education, wide experience, five years in Orient, design, construction, installation and operation, power, light and industrial plants, steam, hydro-electric. Special experience all kinds electrical apparatus and equipment, turbines, boilers, auxiliaries, high tension transmission, substations, distribution systems, building construction, mill machinery in public utility and industrial plants. Available short notice. Location immaterial. C-408-127.

GRADUATE ELECTRICAL ENGINEER AND MECHANICAL ENGINEER, 27, married, one year G. E. test, one year of substation design with large public utility. Work consisted mostly of switchboards, control and protection schemes, and checking drawings. Available on reasonable notice. Location, Middlewest or East. C-1068.

MECHANICAL ELECTRICAL ENGINEER, married, eighteen years' experience covering General Electric test, substation and power station design and operation for steel and wire mills, electrical cable manufacturing and sales. Executive and industrial development ability. A-4652.

SALES ENGINEER, 34, well acquainted with Eastern public utilities, and large electrical jobbers; twelve years' experience. At present connected with large manufacturer of line material and substation equipment. Salary and expenses. Available June 30th. C-1551.

EDITOR-ENGINEER, will edit house organ for transportation company, public utility company, manufacturing company, or get up catalogue, advertisements or historical booklet or descriptive matter. Three and one-half years' experience as department editor of magazine, and electrical engineer of a number of years' standing. C-1490.

GRADUATE ELECTRICAL ENGINEER, Canadian, 27, married, finished Alexander Hamilton Institute Modern Business Course. Three years naval wireless work, Canadian General Electric Students' Test Course, nine months operating department, two years electrical design on hydraulic generating stations. Wishes position as engineer or executive with small growing manufacturing company or public utility. Location, Eastern States. Available fifteen days' notice. C-1524.

ELECTRICAL ENGINEER OR EXECUTIVE, twenty years' experience in electrical design and construction of generating and substations, also transmission and distribution, also industrial installations. Can also sell electrical equipment and commercial power. Desires responsible executive position. Permanence more important than location. B-3711.

LICENSED ELECTRICAL CONSTRUCTION ENGINEER, at present employed electrical field superintendent of large firm doing heating, plumbing, electrical contracting business. Four years' experience with above firm estimating, sales, purchasing, seven years with large public utility electrical engineering and new business departments. Minimum salary $5000. Location, New York or vicinity. Available reasonable notice. C-1548.

RADIO COMPASS ENGINEER, technical graduate, desires position with reliable concern in this capacity. Present employed by U. S. Navy Department on position and direction finding radio. C-723.

ASSISTANT EXECUTIVE, B. S. and E. E. degrees, five years' well balanced experience in all phases of distribution and power substations and their commercial aspects, and one year's experience in administrative office of manufacturing company, three years in supervisory capacity. Desires position with electrical company requiring technical, commercial, and executive ability. Minimum salary $3600. Location preferred, lower Great Lakes States. B-7315.

ELECTRICAL ENGINEERING GRADUATE, (B. S. in E. E.) 30, single, ten years' electrical construction and maintenance of industrial plants, substations, etc., one year electrical design. Desires position in electrical construction with public utility or contracting company. Field work preferred. Minimum salary $2600. Eastern location. C-1525.

POWER ENGINEER, 38, married, electrical graduate, also special study M. I. T., Allis-Chalmers test, 13 years' experience installation power plant machinery, maintenance, general construction, operation and supervision in public utility. Desires position distribution engineer with a public utility or similar work with opportunity for advancement. Location, United States. Available at once. A-4018.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

ASSOCIATES ELECTED JUNE 23, 1926

*ALBERTI, JOHN NORMAN, Designing Engineer, General Electric Co., Schenectady, N. Y.
ALEXANDER, R. WARREN, Elec. Engg. Dept., Commonwealth Power Corp., Jackson, Mich.
ALLEN, JAMES GILLESPIE, Illuminating Engineer, Duquesne Light Co., 800 Duquesne Bldg., Cecil Way, Pittsburgh, Pa.
ALLISON, ROY S., Dist. Manager, Niagara, Lockport & Ontario Power Co., Macy Bldg., Avon, N. Y.
AMBROSE, LEE O., Mech. & Elec. Engineer, The Austin Co., 16112 Euclid Ave., Cleveland, Ohio.
AMES, ALBERT WILSON, Salesman, Lighting Dept., City of Seattle, Seattle, Wash.
ANDERSON, HAROLD LESLIE, Resident Engineer, Commonwealth Power Corp., 244 Michigan Ave., W., Jackson, Mich.
ANDREWS, CHARLES L., Engineer, The Pacific Tel. & Tel. Co., 15 North Park St., Portland, Ore.
ANSON, EDWARD HIRAM, Asst. Engineer, Gibbs & Hill, Pennsylvania Station, New York, N. Y.
*ANTHONY, ROYAL BAKER, Asst. Division Supt., Penna. Power & Light Co., South Oak St., Mt. Carmel, Pa.
ARBUCKLE, JAMES STEWART, Electrical Engineer, American Brown Boveri Electric Corp., Camden, N. J.
ATKINSON, JOHN NORMAN, Hydro-Elec. Power House Operator, Newfoundland Power & Paper Co., Ltd., Deer Lake, Newfoundland.
ATWOOD, DAVID STODDARD, Elec. Engg. Dept., Llewellyn Iron Works, 1200 N. Main St., Los Angeles, Calif.
AUTEN, LLOYD D., Operator, Cleveland Railway Co., Cleveland; res., East Cleveland, Ohio.
BALLANTINE, ROBERT A., Salesman, Penn Electrical Engineering Co., 517 Ash St., Scranton, Pa.
BALLARD, WILLIAM CYRUS, Jr., Professor Elec. Engg. Dept., Cornell University, Franklin Hall, Ithaca, N. Y.
BARTHOLOMEW, FRANCIS JOHN, Director of Bartholomew, Montgomery & Co., Ltd., 614 Standard Bank Bldg., Vancouver, B. C. Can.
BARTON, SYDNEY, Chief Operator, Federal Telegraph Co., Clearwater; res., Long Beach, Calif.
BAUDRY, RENE ANDRE MARCEL, Draftsman, Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., Wilkinsburg, Pa.
BAYLES, CHARLES GILBERT, Engineer, Black & Veatch, 701 Mutual Bldg., Kansas City, Mo.
BEAUMONT, LEONARD, Asst. Engineer, Distribution Dept., Shanghai Municipal Electricity Dept., Foochow Road, Shanghai, China.
*BECKETT, RUSSELL VOHR, Oscillograph Engineer, Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., Pittsburgh, Pa.
BELL, CHARLES REGINALD, Junior Engineer, Cleveland Electrical Illuminating Co., 1013 Illuminating Bldg., Cleveland, Ohio.
BENNETT, JOHN WILLIAM, Distribution Engineer, Eastern N. J. Power Co., Allenhurst, N. J.
BERGHOLTZ, HERMAN, Jr., Testing Dept., General Electric Co., Schenectady, N. Y.
BETTINGER, LEROY WILLIAM, Electrician's Mate, Second Class, U. S. N., U. S. S. *Concord*, c/o Postmaster, New York, N. Y.
BINDER, GURDON A., Salesman, Ohio Brass Co., 1714 Fisher Bldg., Chicago, Ill.
BISAZZA, RUGGERO, Testing Dept., General Electric Co., Schenectady, N. Y.
BISHOP, LOUIS EDWARD, West Penn System, West Penn Bldg., Pittsburgh, Pa.
BLANCH, FREDERICK D., Electrical Engineer, Alternating Current Engg. Dept., General Electric Co., Schenectady, N. Y.
BORGESON, SIDNEY E., Electrical Development Engineer, Western Electric Co., Inc., Hawthorne Station, Chicago, Ill.
BOTHWELL, FORDYCE ARGO, General Electric Co., Schenectady, N. Y.
BOURA, FELIX G., Asst. Engineer, West Penn Power Co., 14 Wood St., Pittsburgh, Pa.
*BOYER, WILLIAM ARTHUR, Test Man, General Electric Co., Schenectady, N. Y.
BRAGG, ARTHUR DICKINSON, Testman, General Electric Co., Schenectady, N. Y.
BRENNON, LEONARD A., Chief Operating Engineer, General Electric Co., Erie, Pa.
BRISTOW, THOMAS NORWOOD, Salesman & Manager, H. B. Squires Co., 552 First Ave., Seattle, Wash.
BROUGHTON, WILLIAM GUNDY, Student Engineer, General Electric Co., Schenectady, N. Y.
BROWN, FREDERICK WILLIAM, 3rd Operator, Public Works Dept., Mangahao Power Station, Shannon, N. Z.
BROWN, LOWELL, Asst. Distribution Engineer, City of Seattle, Lighting Dept., County City Bldg., Seattle, Wash.
BUERY, GEORGE EVERETT, Chief Electrician, Peninsula Lumber Co., McKenna Ave., Portland, Ore.
BURCKETT, DOUGLAS MELLEN, Asst. Engineer, Great Northern Railway, Seattle, Wash.
BURT, ARCHIE RAY, Supervisor, Substations, Underground Trans. Constr. & Maintenance, Kansas City Railways Co., 8th & Woodland, Kansas City, Mo.
BUSTILLO, FRANCESCO E., Electrical Engineer, Mexican Light & Power Co., Gante No. 20, Mexico D. F., Mex.
BUTLER, WILLIAM COOK, Engineer, The Pacific Tel. & Tel. Co., 800 Fairview Ave., N., Seattle, Wash.
BUTT, FRANK HENRY, Sales Correspondent, Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., Dormant, Pittsburgh, Pa.
BUTTERFIELD, HOLLIS SPURGEON, Electrician, Atlantic City Electric Co., Kentucky & Pacific Aves., Atlantic City, N. J.
CAMPBELL, ALFRED E., Foreman, Underground Cable Div., Distribution Dept., The Ohio Power Co., Canton, Ohio.
CAMPBELL, THOMAS LORNE, Estimator, Toronto Hydro-Electric System, Duncan & Nelson Sts., Toronto, Ont., Can.
CANGUCU, O. G., Telegraph Engineer, Paulista Railway, Sao Paulo, Brazil, S. A.
CARRICK, JOHN F. C., Resident Agent, General Electric Co., 533 Gluck Bldg., Niagara Falls, N. Y.
CASTRO, LEOPOLDO, Jr., Student Engineer, General Electric Co., Schenectady, N. Y.
CHAMBERS, HENRY DONALD, Electrical Draftsman, Puget Sound Power & Light Co., Seattle, Wash.
CHANDLER, WALTER G., Supervisor of Cable Bureau, Brooklyn Edison Co., Inc., 14 Rockwell Place, Brooklyn, N. Y.
CHENEY, WALLACE E., Engineer, Switchgear Dept., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
CHRISTIANSON, ELMER C., System Operator, Puget Sound Power & Light Co., 1306 A St., Tacoma, Wash.
CIRELLA, LAWRENCE E., Laboratory Assistant, Simplex Wire & Cable Co., Cambridge; res., Arlington, Mass.
*COOPER, RALPH FENIMORE, Electrician, Armature Winder, Miller Rubber Co., Akron, Ohio.
COOPER, WILLIAM J., Electrician, St. Paul's Hospital, 1100 Block Burrard St., Vancouver, B. C., Can.
COSTELLA, ALBERT PIETRO, Electrical Foreman & Partner, The Camden Storage Battery Co., 40 Haddon Ave., Camden, N. J.; res., Philadelphia, Pa.
COULSON, WILLIAM, Engineer in charge of Workshops, The Electrical Installation & Repairing Co., 40 Berry St., Belfast, Irelnda.
CRAGO, PAUL HUGHES, Electrical Engineer, Union Switch & Signal Co., Swissvale; res., Forest Hills Boro, Wilkinsburg, Pa.
CRAVEN, FRANK ELMER, Engineering Assistant, Bell Telephone Co. of Pa., 261 N. Broad St., Philadelphia, Pa.
CRAWFORD, JAMES M., Asst. General Foreman, Testing Dept., General Electric Co., Schenectady, N. Y.
CROCK, ISRAEL Z., Specification Engineer, New England Tel. & Tel. Co., 50 Oliver St., Boston, Mass.
CROWELL, RALPH MILTON, Operator, Utah Power & Light Co., 133 S. West Temple, Salt Lake City, Utah.
CRUMP, LEONARD WADE, Draftsman, Puget Sound Power & Light Co., 1306 A St., Tacoma, Wash.
*CURTIS, GEORGE V., Testing Dept., General Electric Co., Schenectady, N. Y.
CUTHBERT, JAMES TAYLOR, Chief Electrician, Duquesne Light Co., Pittsburgh, Pa.
DAMON, ALFRED C., Test Dept., Simplex Wire & Cable Co., 66 Sidney St., Cambridge; res., Cochituate, Mass.
DAUGHERTY, THOMAS CLARKE, Telephone Traffic Engineer, New England Tel. & Tel. Co., 50 Oliver St., Boston, Mass.
DAVIS, JOHN CASSIUS, Jr., Trouble Dispatcher, Edison Electric Illuminating Co., 1165 Massachusetts Ave., Roxbury; res., Dorchester, Mass.
DAVIS, WILLIAM, Asst. Engineer, Toronto Hydro-Electric System, Toronto, Ont., Can.
DAVISON, CHARLES, Land Line Inspector, Mexican Telegraph Co., Calle de Escandon No. 99, Orizaba, Vera Cruz, Mexico.
DAY, WILLIAM POWELL, Head, Turbine Test Dept., General Electric Co., Schenectady, N. Y.
DEAN, CHARLES PHILIP, Laboratory Supervising Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.; res., Summit, N. J.
DE CELIS, FRANCISCO, High Tension Inspector of Meters, Mexican Light & Power Co., Mexico City, Mex.
DEDEK, FRANK G., Asst., Electrical Laboratory, Burroughs Adding Machine Co., Second Blvd., Detroit, Mich.
DELLINGER, FLOYD ELLIOTT, Overhead Electrical Engineer, Los Angeles Gas & Electric Corp., 810 S. Flower St., Los Angeles, Calif.
DENEEN, ROBERT J., Dist. Sales Manager, Ohio Brass Co., 1714 Fisher Bldg., Chicago, Ill.
DENNIS, WILLIAM EDWIN, Asst. Electrical Engineer, Bombay Baroda & Central India Railway, Church Gate St., Bombay, India.
DERRONE, MARCEL, Electrical Engineer, S. F. de M. D'e. A. Tekka, Gopeng, Perak, F. M. S.
DE VRIES, BERNARD E., Electrical Engineer, Engg. Dept., Duquesne Light Co., Duquesne Bldg., Pittsburgh, Pa.

DICKERSON, FRANCIS ARTHUR, Asst. Engineer, New York Telephone Co., 104 Broad St., New York,; res., Brooklyn, N. Y.
DIEHL, WILLIAM ARTHUR, Asst. Maintenance Engineer, National Malleable & Steel Castings Co., Cleveland, Ohio.
DOANE, PHILIP, Electrical Tester, New York Edison Co., 92 Vandam St., New York; res., Brooklyn, N. Y.
DODDS, VINCENT G., Local Manager, Aluminum Co. of America, 100 State St., Albany, N. Y.
DOWE, GEORGE PHILLIPSON, Draftsman, The Canadian Crocker-Wheeler Co., St. Catharines, Ont., Can.
*DREYFUS, JAMES, Equipment Engineer, New York Tel. Co., 360 Bridge St., Brooklyn, N. Y.
DRING, LOUIS GABRIEL, Telephone Inside Man, New York Telephone Co., 15 Dey St., New York, N. Y.
DUEVEL, CHARLES OTTO, Jr., Heating & Ventilating Engineer, Consumers Central Heating Co., 108 E. 11th St., Tacoma, Wash.
DUFFY, LEE, Substation Operator, Puget Sound Power & Light Co., 1428 Boylston Ave., Seattle, Wash.
DUNHAM, DAVID, Engineer, Southland Electric Power Board, Invercargill; res., Gore, N. Z.
EBERHARDT, PAUL WILLIAM, General Safety Inspector, Duquesne Light Co., 435 6th Ave., Pittsburgh, Pa.
EDWARD, JOHN ANDREW, Hydro-Electric Power Station, Snoqualmie, Wash.
EHRKE, ERNEST BORMAN, Outside Salesman, Pacific States Electric Co., 236 S. Los Angeles St., Los Angeles, Calif.
ELLIS, DONALD WAYNE, Chief Electrician, Beech Bottom Power Co., Power, West Va.
ERICKSON, ELLIS O., Engineer, Supply Engg. Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
EVELAND, GEORGE HARMON, Engineer, Feather River Power Co., Hobart Bldg., San Francisco, Calif.
EWING, CHARLES, Electrical Engineer, Louisville Gas & Electric Co., 311 W. Chestnut St., Louisville, Ky.
FAGAN, HENRY JOSEPH, 1555 Walton Ave., Bronx, New York, N. Y.
FALK, VICTOR EMANUEL, Electrical Designer, Stone & Webster, Inc., 147 Milk St., Boston, Mass.
FALOR, HAROLD LEROY, Chief Operator, Northern Ohio Power & Light Co., Terminal Bldg., Akron, Ohio.
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GRAVES, JAMES MADISON, Vice-President & General Manager, Duquesne Light Co., 435 Sixth Ave., Pittsburgh, Pa.

HICKS, LeROY VERNON, Manager, Switchboard & Control Div., Service Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., Wilkinsburg, Pa.
LOTT, HARRY CHICKALL, Engineer, Balfour, Beatty & Co., Ltd., 66 Queen St., London, E. C. 4, Eng.
LOUGHRIDGE, CLYDE HIGBEE, Consulting Engineer, 1900 Euclid Ave., Cleveland, Ohio.
PHILLIPS, ELLIS LAURUMORE, President, E. L. Phillips & Co., 50 Church St., New York, N. Y.
THOMSON, STANLEY ERIE, Operating Supt., Hydro-Electric Power Commission, Niagara Falls, Ont., Can.

TRANSFERRED TO GRADE OF FELLOW JUNE 23, 1926

BEDELL, FREDERICK, Professor of Applied Electricity, Cornell University, Ithaca, N. Y.
BOYAJIAN, ARAM, Electrical Engineer, General Electric Co., Pittsfield, Mass.
DAVIDSON, WARD F., Research Engineer, Brooklyn Edison Co., Brooklyn, N. Y.
FONDILLER, WILLIAM, in charge, General Development Laboratory, Bell Telephone Laboratories, New York, N. Y.
HUBLEY, GEORGE W., Consulting and Advisory Engineer, Louisville, Ky.
MARRIOTT, ROBERT H., Consulting Engineer, New York, N. Y.
RICHARDS, WILLIAM E., Supt., Electrical Dept., Toledo Edison Co., Toledo, Ohio.
STRENG, LEWIS S., Vice-President in charge of Operation, Louisville Gas & Electric Co., Louisville, Ky.
THOMAS, GEORGE N., Contract Engineer and Supt. of Construction, Canadian General Electric Co., Ltd., Toronto, Ont.

TRANSFERRED TO GRADE OF MEMBER JUNE 23, 1926

AMES, NORMAN B., Assistant Professor of Electrical Engineering, George Washington University, Washington, D. C.
BAILEY, RAYMOND, Chief Electrical Designer, Philadelphia Electric Co., Philadelphia, Pa.
BULLARD, WILLIAM R., Assistant Engineer, Electric Bond & Share Co., New York, N. Y.
CAMPBELL, THADDEUS C., Telephone Engineer, Systems Development Dept., Bell Telephone Laboratories, New York, N. Y.
CELIS, ATILIO, Manager-Engineer, San Juan Office of International General Electric Co., Inc., San Juan, P. R.
CHADWICK, RALPH H., Section Head, Transformer Engineering Dept., General Electric Co., Fort Wayne, Ind.
CLEARY, LEO H., Electrical Engineer, Standard Engineering Co., Washington, D. C.
CRESSEY, JOHN A., Control Engineer, South Wales Power Co., Pontypridd, Glamorgan, England.
EDISON, OSKAR E., Associate Professor of Electrical Engineering, University of Nebraska, Lincoln, Neb.
FEDER, JOSEPH B., Electrical Engineer, Chas. Cory & Son, Inc., New York, N. Y.
GARRISON, DWIGHT, Supt., Telephone Dept., Atlantic Refining Co., Philadelphia, Pa.
GAYLORD, JOHN C., Electrical Engineer, Southern California Edison Co., Los Angeles, Calif.
GORDON, LESLIE B., Chief Electrical and Power Engineer, Kelly-Springfield Tire Co., Cumberland, Md.
HALPENNY, R. H., Electrical Engineer' Southern Sierras Power Co., Riverside, Calif.
HAMILTON, JAMES T., Supt. of Equipment, New York, Westchester & Boston R. R., New York & Stamford Ry. Co., Westchester Street Ry. Co., New York, N. Y.
HECHT, J. BERNARD, Outside Plant Engineer, Tri-State Tel. & Tel. Co., St. Paul, Minn.
HEILBRUN, RICHARD, Head of firm, Dr. Richard Heilbrun, Manufacturer of Electric Appliances, Berlin, Germany.
HENTZ, ROBERT A., Electrical Engineer, Philadelphia Electric Co., Philadelphia, Pa.
HESTER, EDGAR A., Transmission Planning Engineer, Duquesne Light Co., Pittsburgh, Pa.
HODTUM, JOSEPH B., Sales Engineer, Pittsburgh Transformer Co., Pittsburgh, Pa.
HOWK, CLARENCE L., Telephone Engineer, International Standards Electric Corp., New York, N. Y.
HULL, BLAKE D., Transmission & Protection Engineer, Southwestern Bell Telephone Co., St. Louis, Mo.
KARCHER, E. KENNETH, Chief Electrical Engineer, Utica Gas & Electric Co., Utica, N. Y.
KENNEDY, S. M., Vice-President, Southern California Edison Co., Los Angeles, Calif.
KEPHART, CALVIN I., Senior Examiner, (Valuation), Interstate Commerce Commission, Washington, D. C.
KNUDSEN, H. A., Electrical & Mechanical Engineer, East Bay Municipal Utility District, Oakland, Calif.
KOCH, M. McK., Supt. Electric Distribution, Public Service Co. of Colorado, Denver, Colo.
LOUIS, H. C., Chief of Research & Test, Consolidated Gas Electric Light & Power Co., Baltimore, Md.
MacNAUGHTON, A. K., Supt. of Distribution, Blackstone Valley Gas & Electric Co., Pawtucket, R. I.
McCLELLAN, LESLIE N., Electrical Engineer, U. S. Bureau of Reclamation, Denver, Colo.
McILVAINE, H. A., Engineer, Cleveland Vacuum Tube Works, Cleveland, O.
McROBBIE, HENRY W., Supt. Substations, West Penn Power Co., Connellsville, Pa.
NELSON, EDWARD L., Engineer, Bell Telephone Laboratories, New York, N. Y.
SIMONS, DONALD M., Development Engineer, Standard Underground Cable Co., Pittsburgh, Pa.
SIMS, WILLIAM F., Field Engineer, Generating Stations, Commonwealth Edison Co., Chicago, Ill.
STEBBINS, ALDEN H., Electrical Engineer, Edward Ford Plate Glass Co., Rossford, Ohio.
STINER, H. WRAY, Commercial Engineer, General Electric Co., Cleveland, O.
VAN BOKKELEN, WILLIAM R., Chief Engineer, Coast Counties Gas & Electric Co., San Francisco, Calif.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before July 31, 1926.

Allen, R. L., Archbold-Brady Co., Syracuse, N. Y.
Anderson, C., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Baeckler, W., National Carbon Co., Lakewood, Ohio
Banks, H. O., Hartford Steam Boiler Inspection & Ins. Co., New York, N. Y.
Bennett, R. S., General Electric Co., Cincinnati, Ohio
Bramblett, P. F., Northwestern Light & Power Co., Sibley, Iowa
Butterworth, R. I., Bristol Gas & Electric Co., Bristol, Tenn.
Carrasco-Zanini, J., Mexican Light & Power Co., Ltd., Mexico, D. F.
Cecchetti, F., General Electric Co., Schenectady, N. Y.
Chang, Z. Z., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Curtis, H. C., Cutler-Hammer Mfg. Co., Milwaukee, Wis.
de Mulinen, E. F. H., American Brown Boveri Electric Corp., Camden, N. J.
Donovan, W., General Electric Co., Ltd., Philadelphia, Pa.
Dunkelberg, P. R., Illinois Central Railroad Co., Chicago, Ill.
Dunlap, B., Ozork Pipe Line, Ponca City, Okla.
Fogg, L. E., American Electrical Works, Phillipsdale, R. I.
Gattiker, C. H., The New York Edison Co., NewYork, N. Y.
Gilbert, C. F., Canadian Crocker-Wheeler Co., Ltd., St. Catharines, Ont., Can.
Gilroy, J. R., Commonwealth Edison Co., Chicago, Ill.
Gray, W. S., Stone & Webster, Inc., Boston, Mass.
Gronvold, I. J., Neil Electric Co., Isleton, Calif.
Haentjens, O., Barrett, Haentjens & Co., Hazleton, Pa.
Hall, I. E., (Member), Roller-Smith Co., Bethlehem, Pa.
Hammond, R. J., The Pacific Tel. & Tel. Co., Los Angeles, Calif.
Hastings, D. F., Rossiter, Tuler & McDonnell, New York, N. Y.
Heintz, W. T., Automatic Electric Co., 427 Bourse Bldg., Philadelphia, Pa.
Herne, W. W., Great Western Power Co., San Francisco, Calif.
Hildebrandt, J. L., Consolidated Elec. Lt. & Pr. Co., Baltimore, Md.
Hudd, A. E., Automatic Electric Inc., Chicago, Ill.
Humphries, P. H., Harvard University, Cambridge, Mass.
Ischinger, A. E., with Joshua R. H. Potts, Philadelphia, Pa.
Jones, R. E., (Member), Hydro-Elec. Power Commission of Ontario, Toronto, Ont., Can.
Kohlhepp, W. S., Cumberland Tel. & Tel. Co., Louisville, Ky.
Larkin, J. J., Brooklyn-Manhattan Corp., Brooklyn, N. Y.
Lessing, O., Counties Gas & Electric Co., Norristown, Pa.
Long, M., Bell Telephone Co. of Pa., Philadelphia, Pa.
MacCormick, C. M. C., General Electric Co., Schenectady, N. Y.
Mahnke, K., Pennsylvania Power & Light Co., Williamsport, Pa.
Mahoney, J. F., Brooklyn Edison Co., Brooklyn, N. Y.
Marquardt, M., Electrician, Passaic, N. J.
Nakamura, H., Toho Electric Power Co., Tokio, Japan; (For mail, Wilkinsburg, Pa.)
Nivin, D. G., (Member), Chief Elec. Inspector, City of Miami, Miami, Fla.
Palm, I. R., Sargent & Lundy, Chicago, Ill.
Patrick, R. A., Truckee River Power Co., Reno, Nev.
Pinckert, W. F., Draftsman, 1264 Bush St., San Francisco, Calif.
Rehwaldt, A. W., Sargent & Lundy, Chicago, Ill. (Applicant for re-election.)
Robinson, C. C., (Member), Member of Firm, C. M. Robinson, Richmond, Va.
Rogers, F. H., Consolidated Gas & Electric Co., Baltimore, Md.
Rudorff, D. W., Mexican Light & Power Co., Ltd., Necaxa, Puebla, Mex.
Scharf, P. B., Goodyear Industrial University, Akron, Ohio
Schuman, J. J., (Member), The Edison Elec. Ill. Co. of Boston, Boston, Mass.
Skelton, W. J., Wisconsin Telephone Co., Milwaukee, Wis.
Souza, V., Contratista de Instalaciones, Mexico City, Mex.
Staggs, N. K., The Telephone Engineering & Equipment Co., Seattle, Wash.
Stotler, E. J., Sears, Roebuck & Co., Newark, N. J. (Applicant for re-election.)

Swanson, E. R., Wisconsin Power & Light Co., Fond du Lac, Wis.
Tandberg, L. G., Wagner Electric Corp., Los Angeles, Calif.
Tillquist, D., New York Telephone Co., New York, N. Y.
Terhune, W. I., Public Service Production Co., Newark, N. J.
Tulloss, J. C., (Member), 50 Vanderbilt Ave., New York, N. Y.
Watts, W. E. G., (Member), Luscar Collieries, Luscar via Edmonton, Alta, Can.
Way, R. S., Worcester Suburban Electric Co., Uxbridge, Mass.
Weaver, R. A., Cincinnati & Suburban Bell Tel. Cincinnati, Ohio
Whisenand, O. B., Citizens Gas Co., Indianapolis, Ind.
White, W. C., (Member), Cumberland Tel. & Tel. Co., Louisville, Ky.
Zorn, F. W., (Member), American Laundry Machinery Co., New York, N. Y.
Total 66.

Foreign

Anthony, P. A. W., with A. E. Harding Frew, Brisbane, Queensland, Aust.
Baxendale, F., British-Thomson Co., Ltd., Rugby, Eng.
Bucktin, F. C., Springs-Ellesmere Power Board, Templeton, Christchurch, N. Z.
Crane, S. F., Southland Electric Power Board, Invercargill, N. Z.
Dobbs, L. J., Southland Electric Power Board, Invercargill, N. Z.
Evans, H. C. H., Newcastle City Council, Newcastle, N. S. Wales, Aust.
Keenan, H. B., Waiarapa Electric Power Board, Carterton, N. Z.
Maneckji, J. B., (Member), Industrial Engr. & Advisor, Bombay, India
Master, J. J., Tata Hydro & Andhra Valley Elec. Pr. Supply Co., Bombay, India
Masu, S., Toho Electric Power Co., Tokio, Japan
Pergler, F., Chief Engineer, City of Prague, Prague, Czechoslovakia
Pradhan, G. K., Baroda State's Power House, Baroda, India
Tzichevsky, J. A., Elec. Station Constr., U. S. S. R. Gov't., Moscow, U. S. S. R. Russia
Wight, W. C., Municipal Electricity Dept., Idgah, Simla, India
Total 14

STUDENTS ENROLLED

Balkow, Cecil, Univ. of Idaho
Billman, Albert G., South Dakota State College
Birkett, Charles M., School of Engg. of Milwaukee
Brienza, Anthony, Columbia Univ.
Brown, Cecil L., Univ. of Idaho
Boynton, Robert D., Stanford Univ.
Caruthers, Lawrence H., Yale Univ.
Caven, Waldo E., Carnegie Tech.
Chable, William J., Virginia Military Inst.
Clendenin, Arthur M., Univ. of Nebraska
Cosentine, Louis G., Univ. of Wisconsin
Curtis Lorin, Univ. of Idaho
Delaplane, R. Reyburn, Purdue Univ.
De Roo, Howard Drummond, Mass. Inst. of Tech.
Dodd, Samuel A., Cornell Univ.
Elliott, Robert G., Univ. of Idaho
Ernsberger, Edward L., Univ. of Idaho
Evans, Edmund A., Rensselaer Poly. Inst.
Fisher, John H., Northeastern Univ.
Francis, M. Clifford, Univ. of Missouri
Haber, Frank L., Univ. of Wisconsin
Hall, Clarence F., Rensselaer Polytechnic Institute
Harman, Leonard F., Univ. of Idaho
Hayward, Doyle E., Univ. of Idaho
Hertsche, Jr., J. C., Stanford Univ.
Hockings, Clarence E., Univ. of Wisconsin
Holbrook, Joseph T., Univ. of Idaho
Immer, William L., Univ. of Kansas
Justus, Chester L., Univ. of Idaho
Kellogg, Cyrene W., School of Engg. of Milwaukee
Kirk, Royal B., Purdue Univ.
Krueger, Adolph, School of Engg. of Milwaukee
Kuntz, William R., Penn. State College
Lamphere, Phineas H., Univ. of Idaho
Lanier, John S., Harvard Univ.
Lebowitz, Samuel, Univ. of Maryland
Lovewell, Kermit M., Univ. of Wisconsin
MacDonald, Charles, Pennsylvania State College
Malpass, Donald, Penn. State College
McKim, James B., Stanford Univ.
Menconi, Leonard, Cornell University
Morris, Edson L., Univ. of Idaho
Mushlitz, Arba R., Univ. of Idaho
Nerenberg, Albert C., Univ. of Michigan
Noecker, Cecil C., Michigan State College
Olmsted, Joseph N., Univ. of Colorado
Olson, Melvin C., Univ. of Wisconsin
Orsborn, Forrest M., Univ. of Colorado
Patchen, Roy R., Univ. of Idaho
Phelps, John C., Michigan State College
Poch, Waldemar J., Univ. of Michigan
Porter, Ralph E., Univ. of Missouri
Ream, John Rodney, Univ. of Utah
Reid, Edward M., Oklahoma A. & M. College
Rutherford, Francis H., Mass. Inst. of Tech.
Samida, David A., School of Engg. of Milwaukee
Schuttler, Norman N., Univ. of Idaho
Snyder, Ralph J., School of Engg. of Milwaukee
Solodoff, Vasily J., Oregon Agri. College
Stanton, Wyllys G., Yale Univ.
Stringham, Reed M., Univ. of Utah
Taylor, Richard H., Univ. of Idaho
Thomason, Jesse L., Univ. of Idaho
Van Denburg, Cornelius G., School of Engg. of Milwaukee
Verderame, John, Northeastern Univ.
White, Martin H., Univ. of Maryland
Wood, Ernest P., Worcester Poly. Tech.
Total 67

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Charles le Maistre, 28 Victoria St., London, S. W. 1, England.
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F. W. Willis, Tata Power Companies, Bombay House, Bombay, India.
Guido Semenza, 39 Via Monte Napoleone, Milan, Italy.
P. H. Powell, Canterbury College, Christchurch, New Zealand.
Axel F. Enstrom, 24a Grefturegatan, Stockholm, Sweden.
W. Elsdon-Dew, P. O. Box 4563, Johannesburg, Transvaal, Africa.

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GENERAL POWER APPLICATIONS, A. M. MacCutcheon
POWER GENERATION, Vern E. Alden
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Kansas City	R. L. Baldwin	S. M. DeCamp, 510 Dwight Bldg., Kansas City, Mo.
Lehigh Valley	W. H. Lesser	G. W. Brooks, Pennsylvania Power & Light Co., Allentown, Pa.
Los Angeles	R. A. Hopkins	R. E. Cunningham, 1725 Camden Ave., So. Pasadena, Calif.
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Niagara Frontier	J. Allen Johnson	A. W. Underhill, Jr., 606 Lafayette Building, Buffalo, N. Y.
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St. Louis	Fred D. Lyon	Ralf T. Toensfeldt, 311 City Hall, St. Louis, Mo.
San Francisco	R. C. Powell	A. G. Jones, 807 Rialto Building, San Francisco, Calif.
Saskatchewan	E. W. Bull	W. P. Brattle, Dept. of Telephones, Parliament Bldgs., Regina, Sask.
Schenectady	W. J. Davis, Jr.	W. E. Saupe, Bldg. No. 41, General Electric Co., Schenectady, N. Y.
Seattle	E. A. Loew	C. E. Mong, 505 Telephone Building, Seattle, Wash.
Sharon	W. M. Dann	L. H. Hill, Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Southern Virginia	W. S. Rodman	J. H. Berry, 1338 Rockbridge Ave., Norfolk, Va.
Spokane	G. S. Covey	Richard McKay, Washington Water Power Co., Lincoln & Trent, Spokane, Wash.
Springfield, Mass.	R. P. King	J. Frank Murray, 251 Wilbraham Ave., Springfield, Mass.
Syracuse	W. C. Pearce	L. N. Street, College of Applied Science, Syracuse University, Syracuse, N. Y.
Toledo	A. H. Stebbins	Max Neuber, 1257 Fernwood Ave., Toledo, Ohio
Toronto	L. B. Chubbuck	W. L. Amos, Hydro-Elec. Power Commission, 190 University Ave., Toronto, Ont.
Urbana	C. A. Keener	J. T. Tykociner, 300 Electrical Laboratory, University of Illinois, Urbana, Ill.
Utah	John Salberg	D. L. Brundige, Utah Pr. & Lt. Co., Box 1790, Salt Lake City, Utah.
Vancouver	A. Vilstrup	C. W. Colvin, B. C. Elec. Railway Co., 425 Carroll St., Vancouver, B. C.
Washington, D. C.	A. F. E. Horn	L. E. Reed, Potomac Elec. Pr. Co., 14th & C Sts., N. W., Washington, D. C.
Worcester	E. T. Harrop	Fred B. Crosby, 15 Belmont St., Worcester, Mass.
Total 51		

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Name and Location	Chairman	Secretary	Counselor (Member of Faculty)
Alabama Polytechnic Institute, Auburn, Ala	J. D. Stewart	I. L. Knox	W. W. Hill
Alabama, University of, University, Ala	C. E. Rankin	Sewell St. John	
Arizona, University of, Tucson, Ariz	C. A. Rollins	J. W. Cruse	Paul Cloke
Arkansas, University of, Fayetteville, Ark	R. McFarland	J. Demarke	W. B. Stelzner
Armour Institute of Technology, Chicago, Ill	H. J. Prebensen	W. A. Dean	D. P. Moreton
Brooklyn Polytechnic Institute, Brooklyn, N. Y	J. C. Arnell	J. H. Diercks	Robin Beach
Bucknell University, Lewisburg, Pa	T. J. Miers	C. A. Rosencrans	W. K. Rhodes
California Institute of Technology, Pasadena, Calif	W. A. Lewis	A. E. Schueler	R. W. Sorensen
California, University of, Berkeley, Calif	C. F. Dalziel	R. S. Briggs	T. C. McFarland
Carnegie Institute of Technology, Pittsburgh, Pa	G. L. LeBaron	H. E. Ashworth	B. C. Dennison
Case School of Applied Science, Cleveland, O	C. A. Baldwin	A. B. Anderson	H. B. Dates
Catholic University of America, Washington, D. C	B. J. Kroeger	J. E. O'Brien	T. J. MacKavanaugh
Cincinnati, University of, Cincinnati, O	F. Sanford	W. C. Osterbrock	W. C. Osterbrock
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Colorado State Agricultural College, Ft. Collins, Colo	C. O. Nelson	D. W. Asay	
Colorado, University of, Boulder, Colo	O. V. Miller	L. E. Swedlund	W. C. DuVall
Cooper Union, New York, N. Y	F. H. Miller	H. T. Wilhelm	Norman L. Towle
Denver, University of, Denver, Colo	Harold Henson	Allea Ohlson	R. E. Nyswander
Drexel Institute, Philadelphia, Pa	E. B. Middleton	W. N. Richards	E. O. Lange
Florida, University of, Gainesville, Fla	O. B. Turbyfill	R. Theo. Lundy	J. M. Weil
Georgia School of Technology, Atlanta, Ga	W. M. McGraw	F. L. Kaestle	E. S. Hannaford
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Iowa State College, Ames, Iowa	P. E. Benner	H. J. Biddulph	F. A. Fish
Iowa, University of, Iowa City, Iowa	L. Dimond	A. C. Boeke	A. H. Ford
Kansas State College, Manhattan, Kan	A. M. Young	John Yost	C. E. Reid
Kansas, University of, Lawrence, Kans	K. R. Krehbiel	K. B. Clark	G. C. Shaad
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Lehigh University, S. Bethlehem, Pa	F. G. Kear	J. H. Shuhart	J. L. Beaver
Lewis Institute, Chicago, Ill	O. D. Westerberg	R. G. Raymond	F. A. Rogers
Maine, University of, Orono, Me	S. B. Coleman	H. S. McPhee	W. E. Barrows, Jr.
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Michigan, University of, Ann Arbor, Mich	M. H. Nelson	S. L. Burgwin	B. F. Bailey
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Minnesota, University of, Minneapolis, Minn.	R. L. Christen	A. A. Lee	H. Kuhlmann
Missouri, University of, Columbia, Mo	M. P. Weinbach	L. Spraragen	M. P. Weinbach
Missouri School of Mines and Metallurgy, Rolla, Mo	W. J. Maulder	R. P. Baumgartner	I. H. Lovett
Montana State College, Bozeman, Mont	T. A. Van Noy	J. A. Thaler	J. A. Thaler
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New York, College of the City of, New York, N. Y	J. Wilson	J. Leipziger	Harry Baum
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Ohio Northern University, Ada, Ohio	M. Heft	P. W. Wadsworth	
Ohio State University, Columbus, O.	Lee P. Doyle	J. S. Hoddy	F. C. Caldwell
Ohio University, Athens, Ohio	N. R. Smith	J. E. Quick	A. A. Atkinson
Oklahoma A. & M. College, Stillwater, Okla.	W. J. Beckett	Lee Rogers	Edwin Kurtz
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Static Condensers.—Bulletin 20286, 4 pp. Describes static condensers for power factor correction on motor circuits of 220, 440, and 550 volts. Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.

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Circuit Breaker Time Limit Attachments. Bulletin 530, supplement, 4 pp. Describes Roller-Smith direct-acting time limit attachments for standard type circuit breakers. Roller-Smith Company, 12 Park Place, New York.

Insulator Protection.—Bulletin, 32 pp., "Taking the 'T' Out of Lightning." Describes Locke grading shield and arcing horn equipment for the protection of insulators. Locke Insulator Corporation, Baltimore, Md.

Power Factor Correction.—Bulletin 146, 24 pp., "Power Factor Correction by the Consumer." Describes the experience of the American Gas & Electric Company with power factor correction. Wagner Electric Corporation, St. Louis, Mo.

NOTES OF THE INDUSTRY

The Master Electric Company, Dayton, Ohio, announces the opening of a district office at 1725 Brandywine Street, Philadelphia, where a stock of motors will be carried. The new office will be in charge of William F. Grau.

Lapp Insulator Co., Inc., LeRoy, N. Y., announces the appointment of the Van Rosen Company, 141 Milk Street, Boston, as representative for the New England territory. The Van Rosen Company also represents the Delta-Star Electric Company and the Packard Electric Company.

The Timken Roller Bearing Company, Canton, Ohio, has promoted G. W. Curtis from industrial equipment engineer to district manager of sales, industrial division, for the Milwaukee territory. Mr. Curtis will work with R. W. Ballentine, who previously handled this territory. S. M. Weckstein succeeds Mr. Curtis as industrial equipment engineer.

The Sangamo Electric Company, Springfield, Ill., announces the appointment of Reginal M. Campbell, special representative, with headquarters at 50 Church Street, New York, who will have complete management of all watthour meter business in the metropolitan district. Mr. Campbell will be assisted by W. S. Boult. T. B. Rhoades will continue in charge of radio and amperehour meter sales as well as of the service department.

The Burndy Engineering Company, New York, manufacturers of high-tension bus equipment, announces the appointment of the H. M. Thomas Company, San Francisco, as California representative. The growth of business in the field, and the necessity of quick action in the filling of orders, led to the appointment of a special representative. Preparations are being considered to warehouse the standard Burndy line of connectors for copper tubing and cable in San Francisco, thus establishing a quick shipping point for the west coast.

Banks Huge Investors in Electric Utilities.—In the first four months of this year the financial institutions of the United States, which includes insurance companies, savings banks, national and state banks and trust companies, invested more than $427,000,000 in the bonds of the electric utility industry. In the same four months more than $68,000,000 of electric utility shares were sold to the public. That total of $495,000,000 invested in the electric industry does not include many millions of dollars of securities distributed through the customer-owner plan. The total electric utility stock and bond issues from June 1, 1925 to May 1, 1926, was $979,000,000.

The Conowingo Project—Giant of Hydroelectric Developments.—Second only to that of the Niagara Falls Power Company, and surpassing Muscle Shoals, will be the enormous hydroelectric plant which is being built by Stone and Webster for the Philadelphia Electric Power Company on the Susquehanna River, within four miles of tidewater in the state of Maryland. A dam 4800 feet long—three hundred feet longer than the Muscle Shoals dam—is being built across the river to form a reservoir of 8100 acres. The impounded water will drive waterwheel-driven electric generators of large size, and the energy will be sent over high voltage transmission lines into Philadelphia, 75 miles away.

Ultimately this hydroelectric station will contain 11 generators, each rated at 50,000 horse power, or 36,000 kilowatts. The initial installation will include seven of these units, giving the station 350,000 horse power; the Niagara Falls Power Company development produces 452,500 horse power, and Muscle Shoals 260,000 horse power. Four of the huge waterwheel-driven generators for Conowingo are now being made by the General Electric Company. They are technically rated at 40,000 kilovolt-amperes, 90 per cent power factor, and 13,800 volts, with a speed of 81.8 revolutions per minute. It is expected that 1,360,000,000 kilowatt-hours of energy will be produced by the Conowingo plant in the average year; three-quarters of a million tons of coal a year will be saved thereby.

The electric current, produced by the generators at 13,800 volts, will be stepped up to 220,000 volts by transformers and at this pressure sent over two transmission lines to Philadelphia. Each line will have sufficient capacity to carry the full load in case of trouble with the other one. When the final four generators are added to the power station, a third transmission line will be constructed.

The Conowingo hydroelectric development will be coordinated with the great steam-turbine generating plants of the company so that the water power will be used to supply the base load of the system when the flow of the river is ample, and the steam stations to supply the peak load. When the river flow is low, the steam stations will be used for carrying the base load, and the water power will be called upon only for peak loads. When the river flow is sufficient for full operation, Conowingo will supply 231,000 kilowatts for base load; when the river is low, the enormous reservoir will be called upon, and statistics covering a period of 35 years show that in the driest period of the year Conowingo will be able to supply 190,000 kilowatts for peak loads.

Construction of the 8100-acre reservoir means that the little town of Conowingo, with 200 inhabitants, must be abandoned; fifteen miles of a line of the Pennsylvania Railroad must be relocated; and five miles of main highway from Baltimore to Philadelphia must be built, with a bridge over the dam to replace the one which will be submerged.

The Susquehanna watershed of 27,000 square miles includes a large part of the central section of Pennsylvania, considerable of southern New York state, and a bit of northeastern Maryland. The average river flow is 40,000 cubic feet per second.